NASA Technical Memorandum 102264

RESEARCH AND TECHNOLOGY 1989

Ames Research Center
Moffett Field, California

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NASA

Introduction

Each year, brief summaries of selected achievements at both the Ames-Moffett and Ames-Dryden sites of Ames Research Center are compiled as a NASA technical memorandum.

This report for 1989, now called Research and Technology 1989, presents some of the challenging work recently accomplished in the areas of Aerospace Systems, Flight Operations and Research, Aerophysics, and Space Research. Here, you may sample the scope and diversity of the research that is now being done and the stimulating challenges that will be met in the future.

If you wish further information on any of the Ames research and technology programs, call the number(s) at the end of each article.

Dale L. Compton
Director

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For additional information on any article, you may telephone the Ames-Moffett or Ames-Dryden contact given at the end of each article. The commercial telephone number is shown first, followed by the number for the Federal Telecommunications System, FTS.

Authors of all articles (with the exception of those from the Research and Engineering Division of the Flight Operations and Research Directorate, which is located at Ames-Dryden) are located at Ames-Moffett.

The sponsoring Headquarters program office is listed at the end of each article.

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Aerospace Systems

Aviation Technology Computer Modeling and Analysis

L. Alton

EMS mission analysis for rotorcraft

An evaluation of the potential advantages of the tilt-rotor vehicle technology for a specific emergency medical service (EMS) application has begun. The feasibility of rotorcraft-based EMS in the Caribbean Basin was assessed using data on population, motor vehicles, and motor vehicle accidents.

A discrete event Monte Carlo simulation model permitting a comparative analysis of conventional rotorcraft and the tilt-rotor aircraft as EMS vehicles was developed for use on a personal computer. The model can be used to evaluate other types of vehicles in different regions performing different types of missions. This model was used to compare the relative performance of these vehicles and evaluate the required number and location of EMS centers and rotorcraft in Puerto Rico and the Lesser Antilles.

For EMS missions, the model accepts as input data the locations and categories of hospitals, the number and capacity of rotorcraft at each hospital, the region in which a given percentage of accidents will occur, and other data relating to rescue time, response time, etc. Output of the program includes the average wait time before an accident victim is reached, the average rescue time before the victim is taken to the nearest appropriate hospital, the number of accident victims which are not rescued due to the lack of an available rotorcraft, and the number of hours per week that each rotorcraft spends flying.

The simulation analyses indicated that two tilt-rotor vehicles could perform more effectively for the region than three helicopters, with significantly less average rescue time and fewer out-of-range accidents.

Alternate node transportation analysis

A computer program, Alternate Node Transportation Analysis (ANTA), is being developed for the Macintosh computer by the University of Puerto Rico. It will analyze the effects of adding an alternate node to an existing transportation network on the shipping of individual products or product groups. ANTA can be used to project the value of adding a vertiport to any existing transportation network. In particular, it will illustrate the costs and benefits of a vertical takeoff and landing service for shipping cargo and/or passengers.

For those cases in which both time and money are saved or lost, the dollar-hour figures will be provided. In the more interesting case that the use of the alternate node provides a faster, albeit more expensive, transportation technology, ANTA will determine the time value required to justify the additional expense. An average time will be computed for product groups based upon an expected distribution of relative shipping quantities.

A tilt-rotor feasibility study by the Economic Development Administration of Puerto Rico will use these models and the results of this research.

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International Aviation Technology Studies

L. Alton

International aviation technology markets and resources

Data on the world aviation market (such as research and development, education, capital expenditures, forecasts, aircraft type, companies, agreements, applications, civil or military, employment, trade balance, etc.) have been collected and sources have been identified. Important trends which may have implications for U.S. technology have been identified, and the potential for developing forecasting models will be assessed. Informal documents on some countries and related subjects have been produced and a Hypercard filing system has been developed for retrieving documents.

Cooperative aircraft development in Europe

A preliminary study has been completed on the Airbus Industrie consortium's successful development of civil jet aircraft to compete in the global marketplace. The development history, organization and financial structure, production system, marketing strategy, and the reasons for its success are discussed. Also addressed are problems facing the consortium, differences between American and European support of aerospace industries, and the relationship of Airbus to the European Community organization. Information on and comparisons with the Eurofar organization (a cooperative program involving European countries) to develop a tilt-rotor aircraft are included.

International vertical and short takeoff and landing experience and potential

Several vertical/short takeoff and landing (V/STOL) operations have been analyzed and the potential and lessons for using tilt-rotor aircraft have been assessed. Preliminary analyses covered Canada's current city center V/STOL operations including the Toronto Stolport and the Vancouver/Victoria heliports, the 1974-76 short takeoff and landing (STOL) demonstration between Montreal and Ottawa, and potential tilt-rotor applications. The London Stolport and helicopter service has been reported, in addition to the European transportation infrastructure including high-speed rail networks and implications for future tilt-rotor service. Discussions with the Canadian government have resulted in Canada funding nationwide studies of the benefits of tilt-rotor aircraft applications.

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Correlation of Computational Fluid Dynamics and Flight Test Results

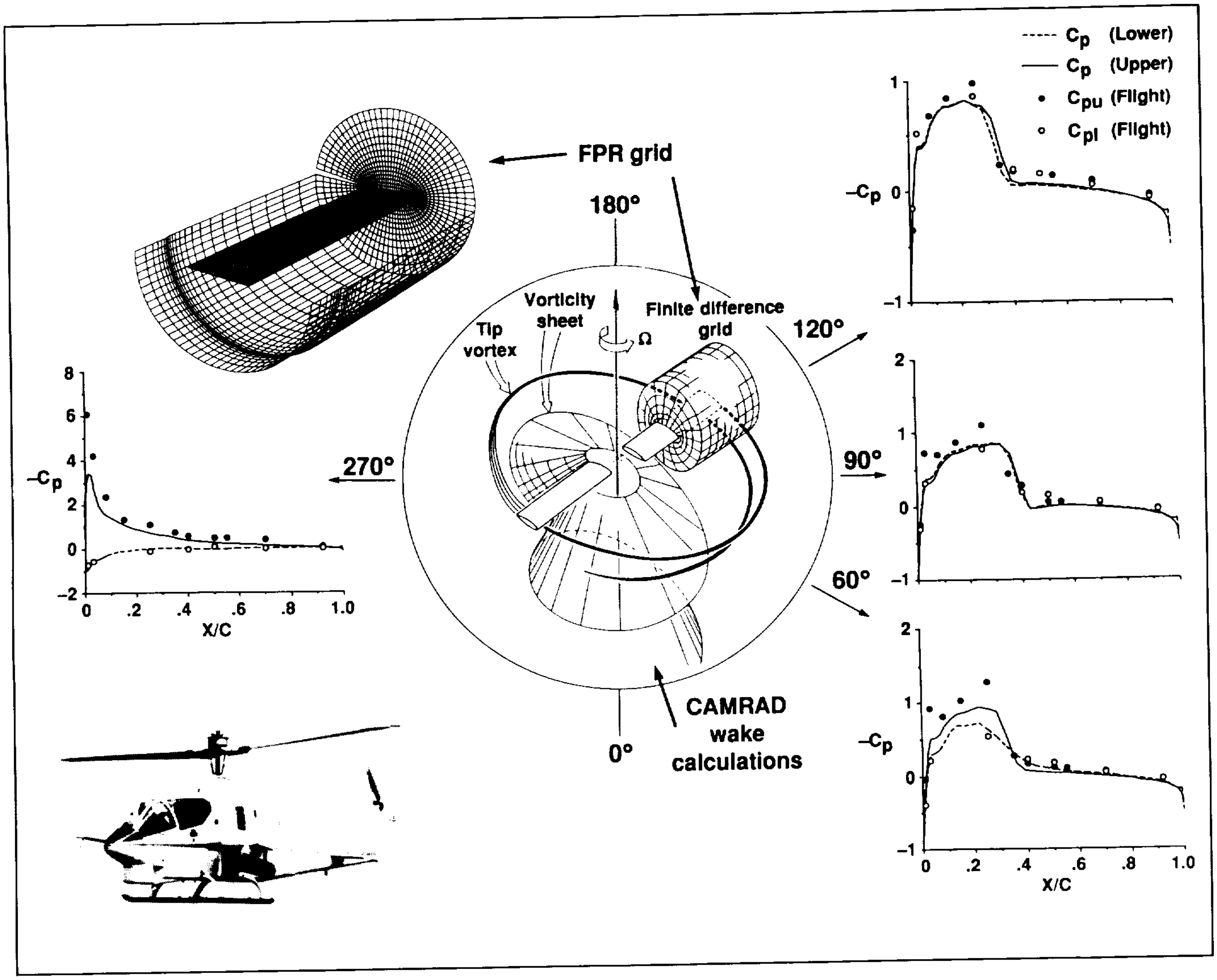
J. Cross, F. Hernandez

An objective of Ames Research Center's Rotorcraft Technology Branch is to evaluate the capabilities of computational fluid dynamics (CFD) codes in correctly predicting rotor airloads. This evaluation is an integral part of the branch's rotor research.

The first code to be investigated is the Full Potential Rotor (FPR) code, which is designed to be coupled with the Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics (CAMRAD). It is compared with the data obtained in the Tip Aerodynamics and Acoustics Test (TAAT), conducted by NASA using an AH-1G aircraft.

The process involves two steps. The first step is to model the aircraft for CAMRAD and achieve a trimmed solution. An iterative approach is used to correct the math model of the aircraft to most accurately predict trim. The numerical results of the rotor wake trim are input to FPR, which computes blade airloads. The results are then correlated with TAAT flight test results, as shown in the figure.

Upon validation of the ability of CFD codes to predict rotor airloads, they will be incorporated into the design process, resulting in improved product capabilities.



Correlation studies FPR/CAMRAD with AH-1G airloads, 159 knots and 96% radius

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Study of a Propulsion System for a Supersonic STOVL Research Aircraft

D. Giulianetti, D. Riddle

An Ames Research Center contract with Pratt and Whitney of United Technologies Corporation to evaluate a derivative of the PW5000 engine as a candidate engine for an integrated aircraft/propulsion system for a potential supersonic short takeoff and vertical landing (STOVL) flight-research/proof-of-concept demonstrator aircraft has been completed. The program was a cooperative effort with the Defense Advanced Research Projects Agency (DARPA) and the U.S. Air Force.

Four powered-lift propulsion systems were considered: vectored thrust, ejector augmentor, remote augmented-lift system, and hybrid tandem fan. The contracted effort included three authorized tasks: (1) concept definition and tradeoff studies, (2) reaction control system (RCS) bleed tests, and (3) concept aircraft integration.

Study results indicate that the PW5000 core has sufficient power to adapt a new low spool and STOVL lift system that would provide sufficient thrust for both vertical landing and levels of in-flight performance anticipated for an advanced, highly maneuverable, supersonic, 35,000-pound takeoff gross weight STOVL aircraft. In the forward (horizontal) flight mode, the PW5000 would operate as a conventional mixed-flow turbofan engine.

In Task 2, a matrix of steady-state and transient RCS bleed airflows were investigated. These ranged from maximum individual bleeds of 13.3% of overall compressor airflow from the compressor interstage, and 10.1% from the diffuser exit (cabin bleed), to combined interstage and diffuser exit bleeds of 8.6% and 10.1%, respectively. No adverse effects on gas generator performance resulted for these bleed conditions which should meet STOVL aircraft RCS bleed airflow requirements.

The contract contained two optional tasks which were not exercised: STOVL supporting engineering tasks (Task 4), and gas generator preliminary and detail design (Task 5). By mutual agreement with the U.S. Navy, the contract, including these optional tasks, was transferred to the Naval Air Propulsion Center for continued performance of engine technology development with Pratt and Whitney related to supersonic STOVL fighter aircraft.

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Electro-Expulsive Deicing System

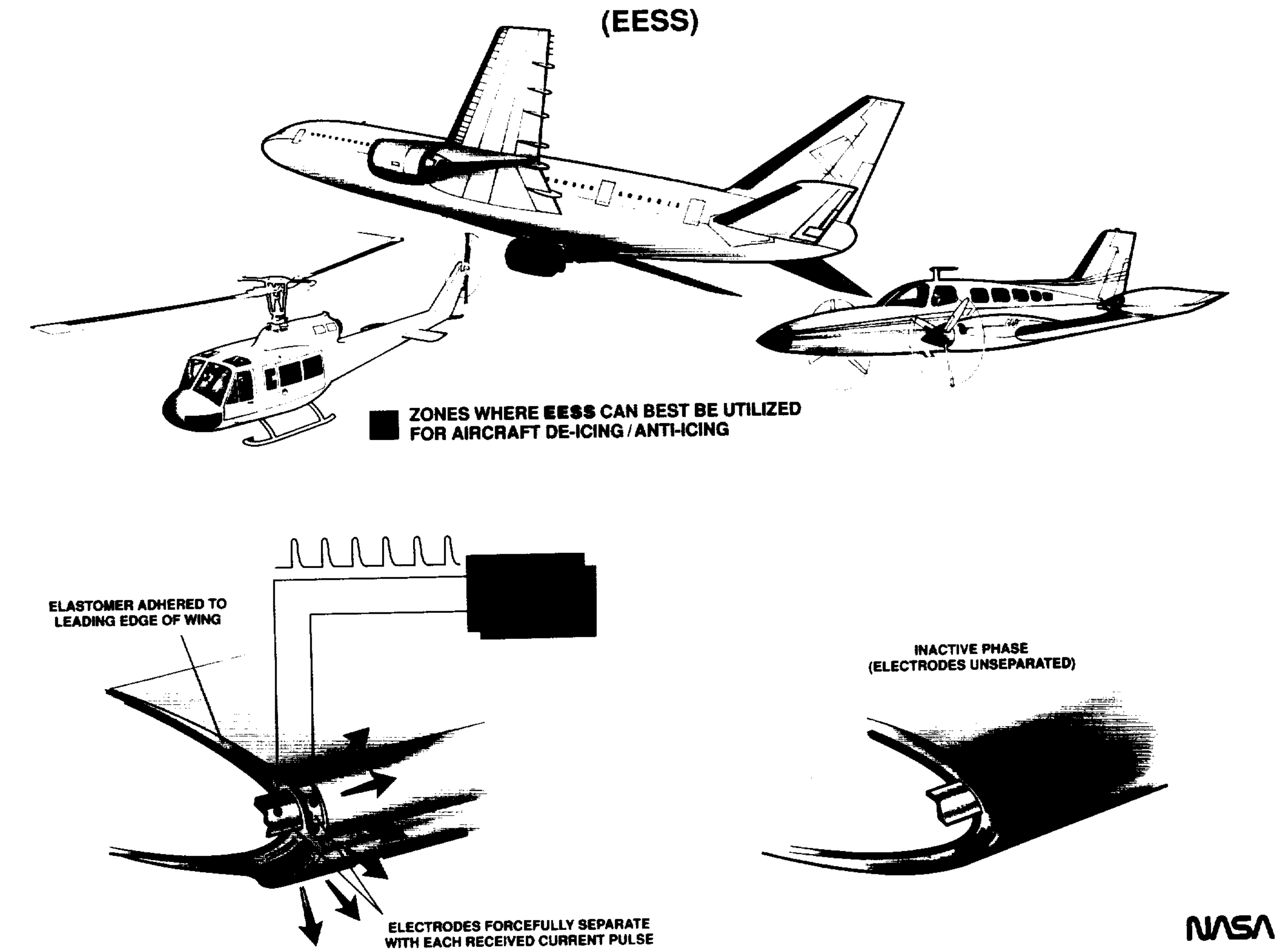
L. Haslim, P. McDonough

Following successful flight tests on an F/A-18 Hornet and Lewis Research Center's Twin Otter, the Electro-Expulsive Deicing System (EEDS) is being prepared for flight tests on a Boeing 727 owned by Northwest Airlines. American Airlines is also interested in an EEDS retrofit for its MD-80/90 series. Employees of both airlines believe that the EEDS's low power consumption, light weight, and retrofitability are its most desirable features.

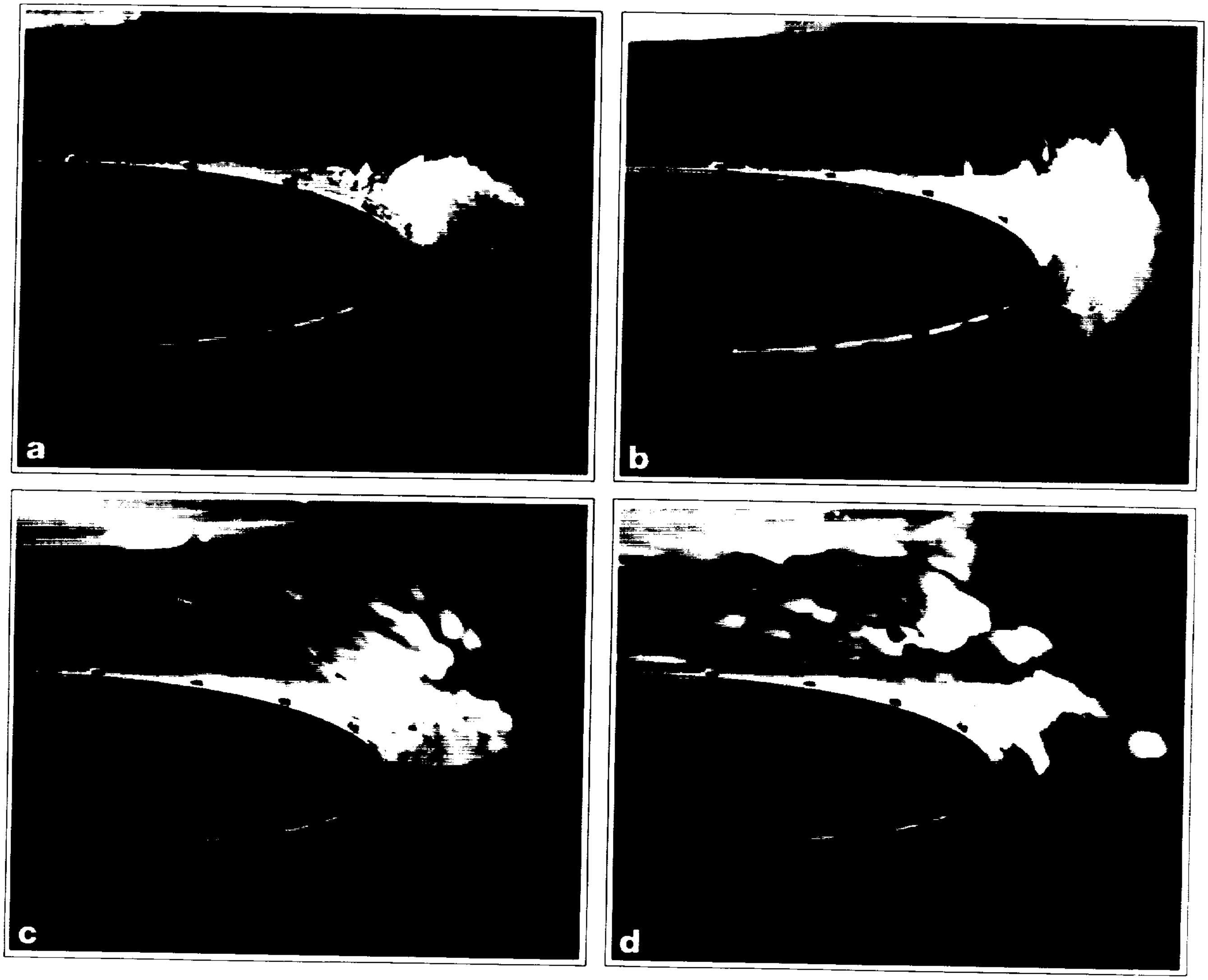
The U.S. Air Force selected the EEDS for providing its B-1B engine inlet ice protection, and funded the airframe manufacturer to conduct an integration analysis to incorporate the Ames Research Center's development expeditiously. The U.S. Navy initiated steps to retrofit critical areas of its ships—personnel doors, vertical launch hatches, and most superstructures—with the EEDS.

The Navy's David Taylor Research Center wants to put an EEDS sample in the Arctic Simulation Chamber in Point Loma, California, to test the durability of the EEDS in cold weather climates. The North Atlantic is an extremely hazardous environment for shipping, and temperatures as low as –85°F can severely hamper Coast Guard rescues and commercial fishing activities. An Aegis-guided Missile Cruiser can rapidly accrete over 1.5 million pounds of ice even in moderate conditions (32°F).

Ames personnel will conduct a second EEDS winter sea trial in the Bering Sea off the Aleutian Islands in late 1990.



Electro-Expulsive Deicing System, a specialized version of the Electro-Expulsive Separation System (EESS)



High-speed photography sequence demonstrating how the Electro-Expulsive Deicing System shatters and ejects ice from a wing model in a wind tunnel test

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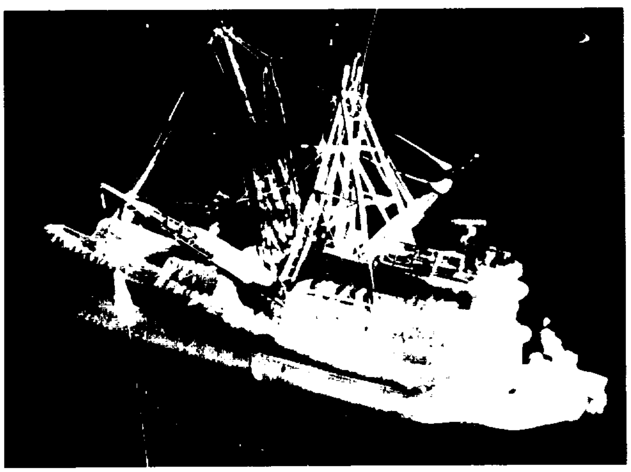
Electro-Expulsive Deicing System Sea Trial Conducted in Alaska

L. Haslim, P. McDonough

Ice accretion poses a serious threat to shipping. Both Naval and commercial fleets are hampered by their inability to operate in icing conditions and the vessel's safety and effectiveness is severely downgraded when it operates in frigid climates. The accumulation of ice causes instability and poor visibility, and can literally sink a ship by sheer mass weight alone (see figure). Dozens of lives are lost at sea each year from ice-related catastrophes.



Alaskan fishing vessel sinking because of large amounts of ice accretion

Because of operational limits and hazards placed upon U.S. Navy ships and northern fishing fleets by icing, a winter sea trial was conducted in late 1989, in the Bering Sea aboard an Alaskan Fish and Wildlife Protection vessel, the largest in the state's fleet. Navy, industry, Ames Research Center, and Alaskan government participants tested the EEDS for 8 days at sea from Kodiak Island to the Pribiloffs in actual sea-icing conditions. The proof-of-concept experiment was successful and, as a result, a joint project has been implemented.

The Navy, favorably impressed with the results, intends to retrofit the EEDS onto key areas of its LCAC (landing craft air-cushioned or hovercraft) and Aegis-guided Missile Cruiser (personnel and missile launch hatches). The Alaskans anxiously anticipate the development of this system that can enhance the safety and utility of their fishing vessels. As a result, the Governor of Alaska has made this joint effort a priority, and has authorized the use of state government vessels in the hopes of promoting this life-saving device.

Ames personnel will continue their effort to enhance safety and operation with the transfer of the EEDS technology and a second EEDS winter sea trial in the Bering Sea in late 1990.

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Passive Chlorophyll Detector

L. Haslim, P. McDonough

Plans to implement an exciting new optical plastic filter system for agricultural and forestry uses are under way. The system is the Passive Chlorophyll Detector (PCD). Through the use of a low-cost, uniquely dyed optical filter plastic sheet, the PCD enhances the visual discrimination of vegetation and trees in varying states of health.

Research goals included investigation of reflectance spectra in the visible region of selected crops and foliage in varying degrees of stress when they were compared to healthy specimens. It then became necessary to optimize the transmittance characteristics of the filter system to maximize the apparent visual color distinctions for each selected type of vegetation. By correlating the transmittance properties of the filters with the spectral reflectance characteristics in the visible region of selected chlorophyll-bearing vegetation specimens, tailor-made filter sets for selected foliage were designed and tested. The PCD demonstrated the ability to provide real-time visual detection and discrimination. Permanent records of the visual discrimination are obtainable by superimposing the PCD onto conventional picture imaging systems.

It was demonstrated that almost any untrained observer can now easily discriminate the visual results of varying degrees of stress imposed upon the vegetation. Farmers and foresters presently develop this skill only through years of experience, and the detecting range is limited at best.

The ability to economically and easily discriminate, evaluate, and record the spectral-reflectance response of vegetation provides immediate information on the condition or health of the plants. The ramifications of such an aid are far-reaching. For example, higher yields of crop production can be achieved when farmers are able to either nurse or replant unhealthy sections of their fields.

From an ecological standpoint, foresters and environmental scientists will be able to better monitor and maintain forests and wetlands which are being exposed to acid rain or contaminated groundwater systems. The trees may appear healthy to the naked eye, but when viewed with the PCD, the early states of destruction will be apparent and countermeasures can be implemented before the tree's condition becomes irreversible.

The Civil Technology Office, in collaboration with a major Fortune 500 materials corporation, are developing plans to transfer and manufacture the PCD technology to the benefit of both the agricultural and ecological communities.

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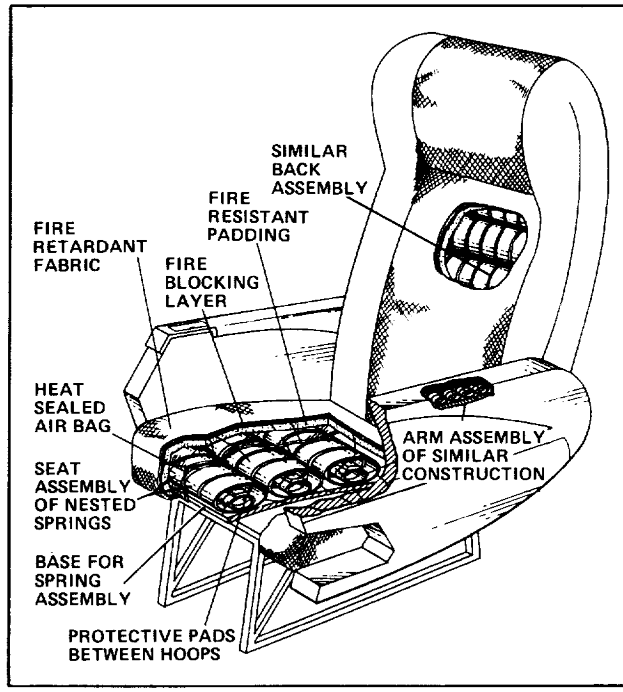
Lightweight, Fire-Retardant, Crashworthy Aircraft Seat Cushioning

L. Haslim, P. McDonough

A unique spring design will enhance both the comfort and safety of plane, train, bus, and automobile seats. The lightweight seat was invented as a replacement for aircraft polyurethane foam seating that emits hydrogen cyanide gas when it is ignited.

The design consists of central, elliptical, tubular-spring supports made of fire-resistant and fatigue-durable composites. The supports are surrounded by a fire-blocking sheath. The cushioning also meets crashworthy standards by incorporating energy-absorbing, visco-elastic layers between the nested, elliptical-hoop springs. Aside from its fire-resistant and energy-absorbing characteristics, the seat cushion is lightweight, economical and simple to fabricate, easily maintained, and structurally strong.

Several airline and automotive corporations have requested that prototypes of the cushioning be built for testing and evaluation, and three Fortune 500 materials companies have applied for manufacturing licenses to produce the cushioning.



Aircraft seat

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Lightweight, Telescoping Rescue Boom for Helicopters

L. Haslim, P. McDonough

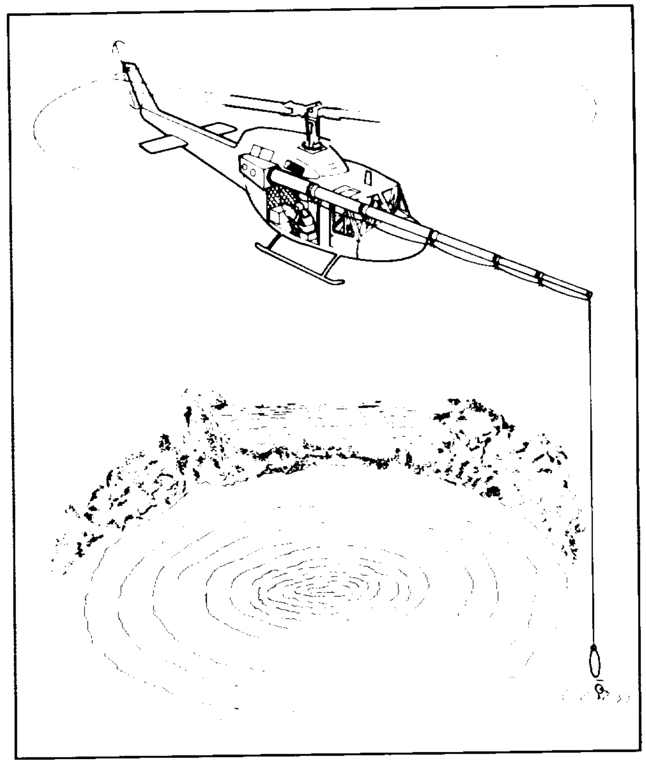
Aircraft has been used for years to rescue pilots downed at sea, as well as sailors or fishermen who have had to abandon a boat or ship. Fixed-wing seaplanes have speed, range, endurance, and payload attributes; however, they cannot land or take off effectively in high-sea states. Helicopters have the unique ability to hover over or near the rescue site, and much work is being undertaken to provide helicopters with all-weather flying capability as well as speed, range, and payload improvements.

The one drawback associated with helicopter rescue operations at sea is the problem caused by the severe blowing action of the main rotor downwash. The victim being rescued is frequently blown away or obscured while the helicopter hovers directly overhead. Some drownings have been attributed to the downwash. Apart from the downwash caused by the helicopter main rotor, it is difficult for the helicopter pilot to see the rescue line when it is dropped behind him as, for example, through a floor hatch.

The SH-60 B Sea Hawk helicopter entering the U.S. Coast Guard inventory does not have the capability of landing in water that its predecessors had. This shortcoming frequently requires crew members to jump into the open sea to effect a rescue, thereby increasing the overall risk. To improve the effectiveness and utility of their search and rescue helicopters, a Memorandum of Agreement exists between NASA and the U.S. Coast Guard to develop an Ames Research Center concept for a lightweight, telescoping rescue boom for these helicopters. Ames has contracted with a leading helicopter corporation to fabricate a prototype version of the Ames rescue boom for flight testing on a Kaman SH-2 prior to flight testing on the Sea Hawk.

Modern composite technology is used to achieve the desired properties. The retractable boom, for which a government patent is pending, is designed to project the existing rescue hoist cable end to the front of the helicopter where it will be within the pilot's vision and beyond the main rotor's downwash. Upon engagement, the cable falls free from the extendable boom and is wenched up in the conventional manner.

Engineers are taught at the beginning of their training that the two most important things to remember are: "F = ma" and "you can't push with a rope." The latter reference to the limp resilience of a rope, and the implied futility of using a material improperly, is one of the cardinal precepts that is slowly learned, and often quickly forgotten. Here, however, the device used to extend and retract the telescoping rescue boom is an innovation that uses



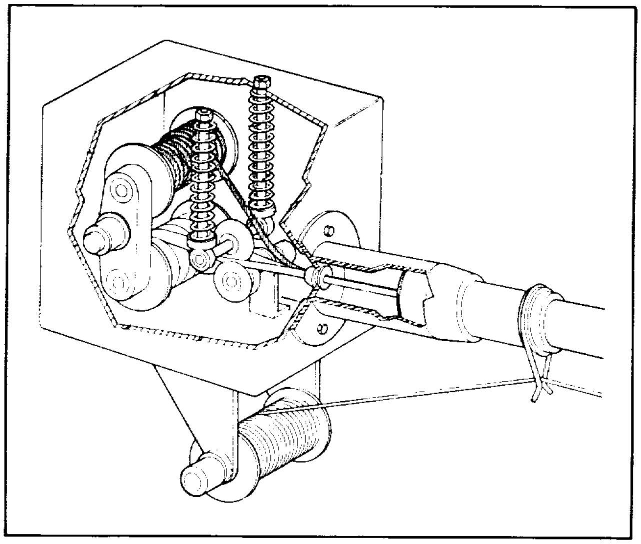
Lightweight, telescoping rescue boom in use

the limpness of a rope where needed, and then imparts a required rigidity to permit violating the above rule—pushing with a rope.

The thin, springy, metal foil strip from the lower reel is caused to form into a hollow tube encasing the flexible, but not compressible, wire rope. The result is a stiff, nonkinking, push-pull rod capable of extending or retracting the rescue boom without a large weight penalty.

Design provisions permit the boom to pivot from the longitudinal axis to the 30°, 45°, and 90° starboard positions as needed. The 90° position coincides with the rotorcraft's main door, where the crewmembers can assist in the rescue. For rescues where tip-path obstructions exist (shipmasts, bridges, buildings), the boom may be extended an additional 3 meters beyond the normal extension. Angled red and green light beams that project horizontally are used to triangulate the proper safe distance (e.g., where they coincide) from the rotor tip to effect the rescue.

Use of this device is expected to greatly improve the rescue capabilities of rescue helicopters confronting conditions such as rough seas, mountainous



Device used to extend and retract the telescoping rescue boom

terrain, and even high-rise building fires. There also may be some space station applications for these devices.

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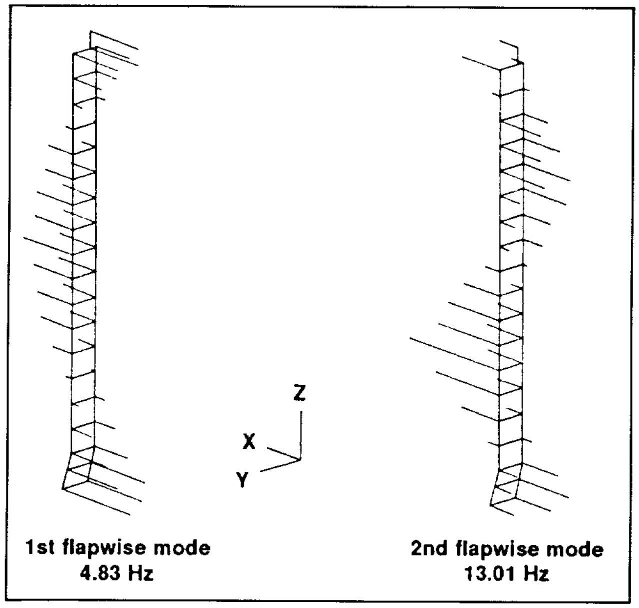
Modal Analysis of UH-60 Instrumented Rotor Blades

R. Kufeld, K. Hamade

The objective of this effort was to verify the dynamic similarities of the UH-60 rotor blades to be used in the Airloads Flight Research Program. The program used a set of five blades. The blade set includes a blade highly instrumented with pressure transducers, a blade with strain gages and accelerometers, and three production blades. In addition, this program will supply information to validate analytical models of the blade structure used in comprehensive prediction codes.

The frequency, damping, and mode shapes of each blade to be flown in the UH-60 airloads program have been measured. From these measurements the dynamic similarities of the blades can be compared. A NASTRAN model of the blades has been developed and correlated with the measured data to validate the blade stiffness model used in comprehensive prediction codes.

A nonrotating shake test of the blades hanging vertically from the root was performed. The data have been analyzed and preliminary results appear in the table. The first two flapping mode shapes of a production blade are shown in the figure.



UH-60 shake test modal analysis

The NASTRAN model has been completed and correlated with the measured results. Excellent correlation was achieved providing high confidence in the blade structural model.

The UH-60 airloads data base will be the first comprehensive four-bladed airloads study conducted by the United States since the late 1950s. Dynamics of all blades used in the airloads program are key elements of this comprehensive data base. The shake test and analysis provided key information about the assumption of dynamically similar blades used in prediction codes. They also verify the structural model used in the prediction codes. Errors in the structural model of the blade or the presence of a nonsimilar blade in flight test could severely hamper correlation efforts when using comprehensive prediction codes.

INSTRUMENTED BLADE MODAL FREQUENCIES (Hz)
1989 SHAKE TEST

Modes	Basic UH-60 blade	Strain gage blade	Pressure blade
1st flapwise	4.83	4.78	4.69
2nd flapwise	13.01	12.74	12.46
3rd flapwise	26.01	25.47	24.87
4th flapwise	42.66	42.01	40.51
5th flapwise	65.45	64.15	62.28
6th flapwise	97.15	96.00	92.72
1st chordwise	26.38	26.00	25.55
2nd chordwise	70.31	69.12	67.37
1st torsion	46.61	45.56	44.49
2nd torsion	85.12	83.88	80.75

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XV-15/Advanced Technology Blades Flight Investigations

M. Maisel, B. Wellman

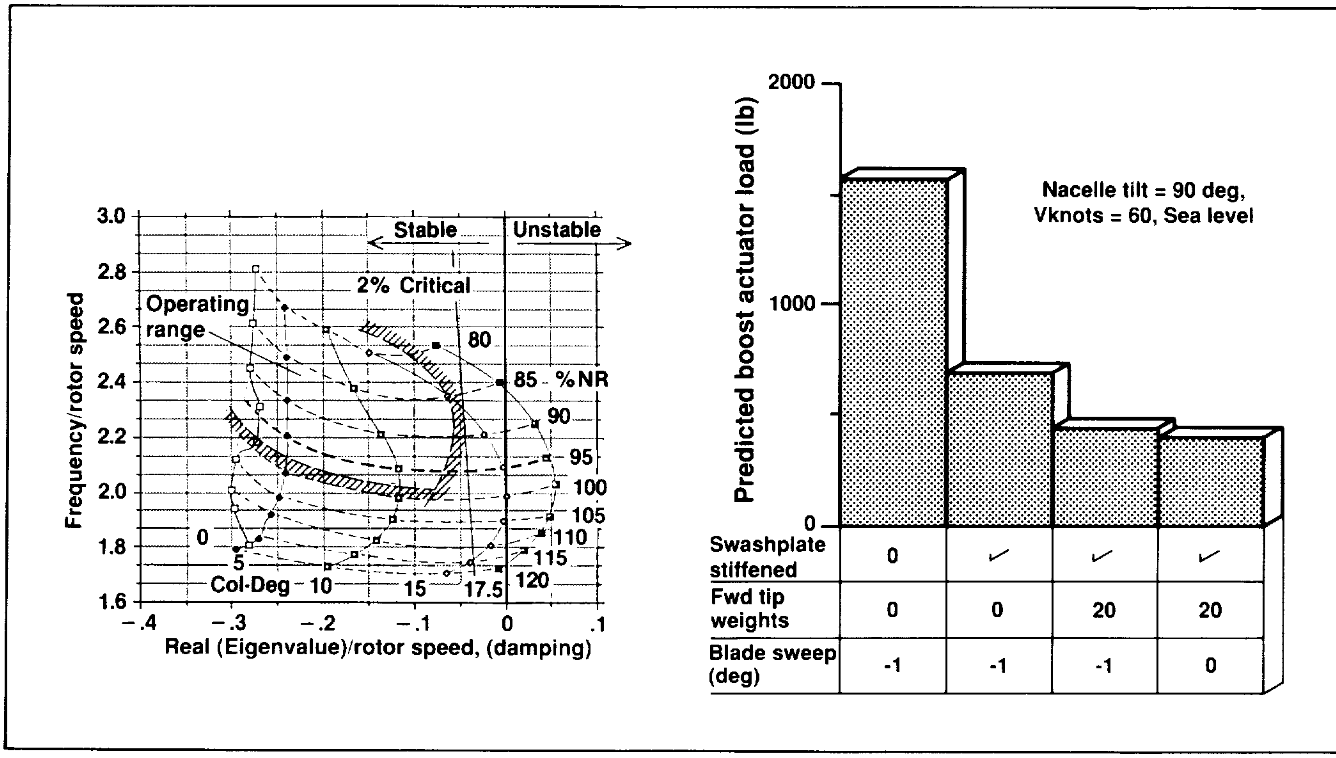
The overall objective of this program is to enhance tilt-rotor flight research and validation efforts in the areas of aerodynamics, and structural and materials technology capabilities through the application of advanced rotor design. Blade geometry variability for research is desired. Flight research goals include investigations of performance, acoustics, dynamics, and aeroelastic stability. An additional major objective of the long-range program is the acquisition of airloads data in all tilt-rotor flight modes for the validation of advanced codes.

A new rotor blade designed using state-of-the-art performance methodology and airfoil sections, and advanced structures and materials, is being tested on the XV-15. The blades are highly twisted with a compound planform and a thin tip for reduced noise and greater lift capability (at high loadings) in the hover mode without degrading performance at high speeds in the airplane mode. The ability to change tip and cuff section geometry as well as blade sweep is also incorporated. Flight and ground tests will provide the opportunity to validate advanced codes such as Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics (CAMRAD).

Initial advanced technology blade (ATB) tests revealed high rotor control loads in the helicopter mode flight. Extensive analyses and experiments determined that the higher feathering inertia of the ATB introduces a resonance in the operating rotational speed range. A previously undocumented XV-15 rotor control system "softness" produces a cyclic/collective coupling that reduces stability. Modifications of CAMRAD to analyze the unique XV-15 control characteristics have been accomplished and analyses of parametric variations to identify a solution have been completed. These analytical studies established an approach for modifying the aircraft to enable operation within the complete XV-15 flight envelope. Based on hangar demonstrations of the ability to shift the resonant frequency, a modification to stiffen the controls was incorporated and ground and flight validation of the modification was completed. Further flight investigations of the effects of blade configuration changes, including blade tips with reduced twist and moving the tip center of gravity forward have demonstrated a reduction of the helicopter-mode control loads to within acceptable levels.

Investigation of the XV-15/ATB rotor/control dynamics has resulted in a greatly increased understanding of the phenomena involved and has accelerated the development of improved methodology for analyzing these phenomena. The validation of this methodology in flight through correlation with flight data will significantly enhance our capability to predict and design for dynamic and aeroelastic phenomena for future tilt-rotor aircraft.

Flight validation of XV-15/ATB control loads reduction



Analytical studies evaluate stability and loads, and identify modifications to reduce XV-15/ATB control loads

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Structural Parameter Identification by Numerical Optimization

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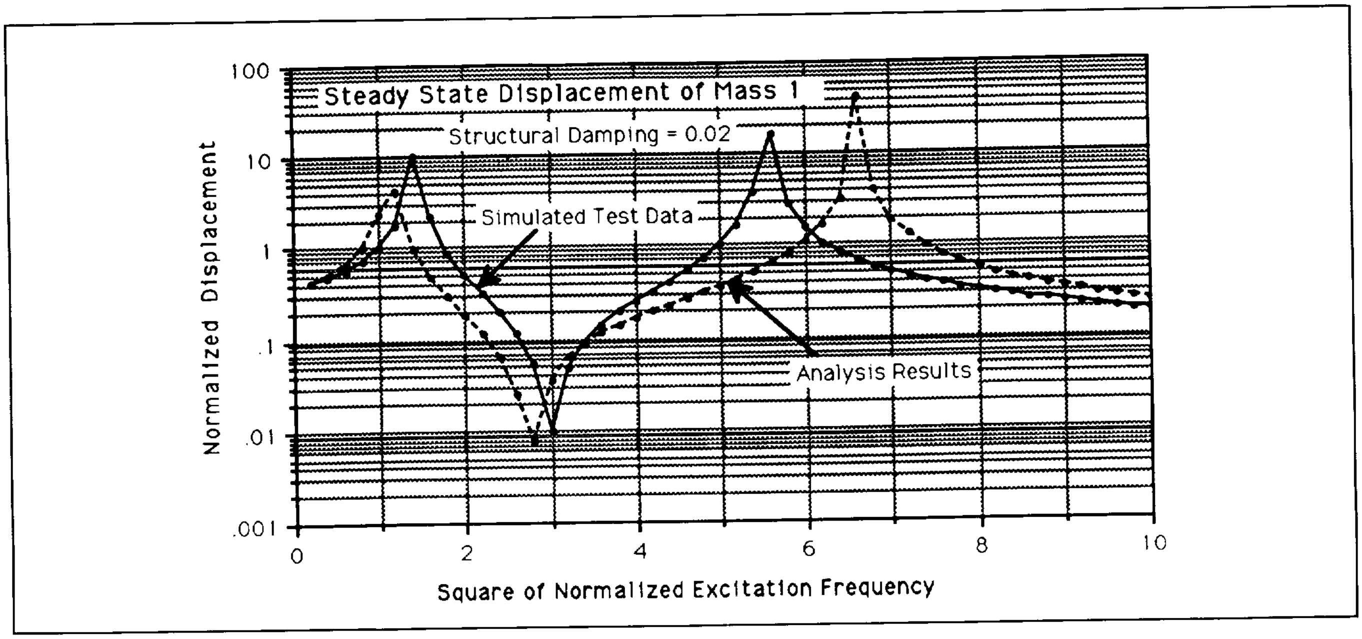
When the results of structural analysis do not agree with the results obtained from tests, various sources of the errors can be considered. In this study, numerical errors in the analysis model parameters are assumed to be the only source of discrepancies and numerical optimization techniques are applied to modify these values. The procedure is implemented to work with a general finite element analysis program, MSC/NASTRAN, so that practical and complex structures can be accommodated. As an illustration, suppose that a harmonic excitation is applied to the base of two masses connected by springs and dampers. When the measured responses and results of analysis do not agree, such as shown in the figure, parameters used in the analysis may need to be adjusted.

In the past, a majority of the studies in dynamic structural parameter identification considered determination of modal properties such as modal stiffnesses and/or modal masses. Although this approach is important in its own right, it does not provide quantitative data specifying how the analysis model parameters must be modified so that the analysis results would be matched with the test results. In the example in the figure, physical parameters such as spring constants and inertia properties can be modified directly as the design variables of the structural optimization procedure.

The program has been applied successfully to relatively simple problems such as the one shown in the figure, in which the magnitudes of responses are



Frequency responses obtained by tests and analysis

given in the frequency range 0.2 through 10.0 at an interval of 0.2. Using only 5 out of 50 frequency data points, the correct parameters are identified starting from any of several different sets of initial values.

Research is continuing to test various forms of error functions applied to frequency responses and their minimization schemes to make the best use of available data and computational resources.

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Advanced Tactical Transport Technology

D. Riddle, D. Ashby

The U.S. Air Force has shown interest in developing a new military advanced tactical transport (ATT) aircraft. Initial mission requirements dictated that this airplane possess vertical and short takeoff and landing (V/STOL) field performance capability or, at the very least, short takeoff and landing (STOL) characteristics superior to those demonstrated during the YC-14 and YC-15 prototype program.

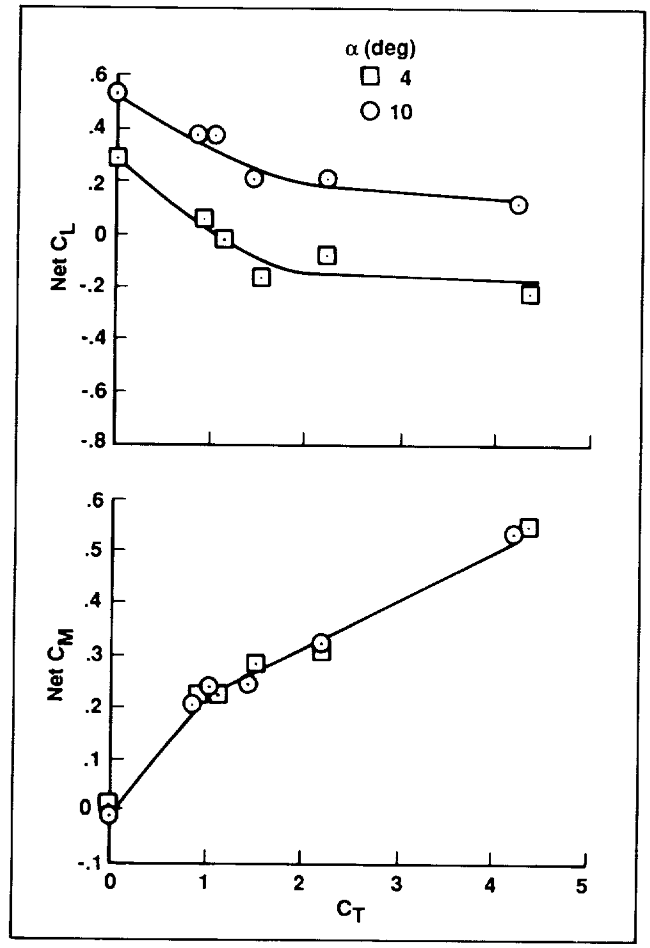
The requirement also exists for efficient subsonic cruise at high and low altitudes. Combining the field and cruise requirements will require the meticulous blending of vehicle aerodynamics, propulsion integration, and stability and control technology.

A well-developed analytical capability will be used to the fullest extent possible during configuration development cycles. However, experimental data must be acquired in the hover and transition flight regimes to quantify the performance level of these advanced transport technology concepts.

Under a Memorandum of Understanding between the Air Force Wright Research and Development Center (WRDC) and Ames Research Center, a cooperative program has been conducted to define transitional flight aerodynamic characteristics of an Air Force-proposed V/STOL ATT configuration. The configuration, which used a lift plus lift-cruise propulsion concept, was theoretically analyzed at Ames using an Ames panel method, PMARC. A wind-tunnel model was designed, constructed, and instrumented for transitional flight aerodynamic testing. Testing began in Ames' 7- by 10-Foot Wind Tunnel and was completed in the Langley Research Center (LaRC) 14- by 22-Foot Subsonic Wind Tunnel.

The first figure shows the semispan model with lift and lift-cruise propulsion simulators in the Ames wind tunnel.

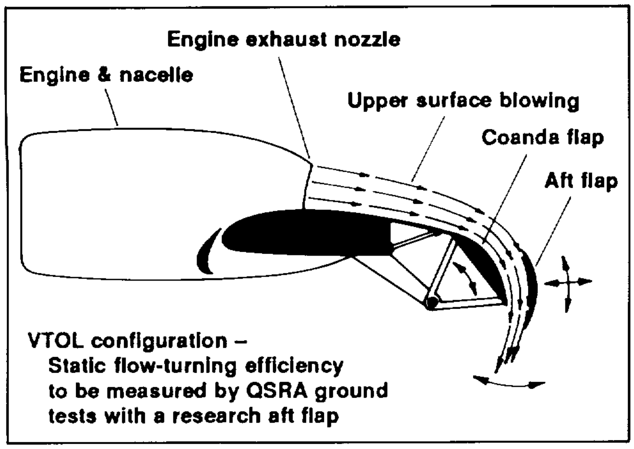
Advanced tactical transport vertical and short takeoff and landing (ATT V/STOL) model installed in Ames Research Center's 7- by 10-Foot Wind Tunnel



Thrust effects on the ATT V/STOL lift and pitching moment

The test results for the model in the baseline lift configuration in the Langley wind tunnel indicate a substantial penalty in net lift and pitching moment increments due to propulsion system power effects as shown in the second figure.

An alternative approach to meeting the Air Force's ATT mission requirements is to develop a configuration with proven superior STOL performance with V/STOL acquired by a modification. The potential for using upper surface blowing with an aft-flap segment to turn the engine exhaust flow through at least 90° is being investigated theoretically and experimentally by Ames researchers. The concept is shown in the third figure. The efficiency of the exhaust flow turning will be assessed in a full-scale static ground test on the Quiet Short-Haul Research Aircraft.



Upper surface blowing V/STOL concept with aft-flap to turn flow 90°

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Supersonic Short Takeoff and Vertical Landing Fighter Takeoff Studies

J. Samuels, P. Gelhausen

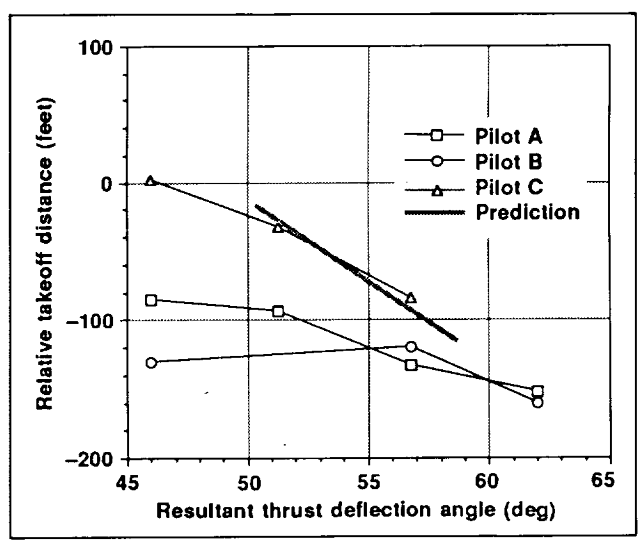
Ski jump and short takeoff (STO) capability is a critical performance measure of future short takeoff and vertical landing (STOVL) fighters and has received significant attention. Ability to adequately predict aircraft performance during this critical flight phase will improve the understanding of STOVL concepts and reduce the risk of proceeding with a Technology Demonstration/Flight Research Aircraft.

A fixed-base, piloted simulation has been completed and several analytical models have been developed. The mixed flow remote lift (MFRL) propulsion concept studied is based on a concept developed for the U.S./U.K. Advanced STOVL (ASTOVL) program under a contract to McDonnell Douglas.

The MFRL was selected for study because it possesses the characteristics considered beneficial by the Joint Assessment and Ranking Team and the Joint Working Group of the U.S./U.K. ASTOVL program. These characteristics are the mixed-flow engine cycle for up-and-away flight and a source of lift located remotely from the engine in hover. In addition, this concept uses unaugmented, fully mixed flow in hover.

Activities include development of both short takeoff and ski jump analysis capabilities in the aircraft design synthesis code, ACSYNT. An additional ski jump simulation code has also been developed. These models were developed to support the fixed-base, piloted simulation of MFRL STO and ski jump which was completed in May 1989. Research objectives of the simulation were to establish operational maximum conventional and short takeoff and ski jump performance for the subject aircraft, and to make a comparison between operational limits discovered and performance predicted with the analytical methods.

Configuration variables considered for STO were aircraft rotation speed, overall thrust vector angle, front nozzle deflection limits from 0 to 20°, and lift improvement devices (LIDs). The figure compares predicted STO performance to that achieved by the pilots. Pilot reaction time, aircraft rotation rate, and landing gear strut extension were found to be critical in predicting STO performance. For ski jump, the effects of runup distance, thrust vector angle, ramp angle, reference pitch attitude, LIDs, and front nozzle deflection limits from 0 to 20° were examined. Exceptional STO and ski jump performance were



Relative takeoff distance as function of thrust deflection angle, lift nozzle deflection = 20°, LIDs on, T/W = 0.94 obtained that met the pilot's acceptability criteria. Ski jump performance is easier to predict than STO performance because there is less pilot-induced variability. Winds and turbulence were introduced with the result that the handling qualities were acceptable in all cases.

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Studies of High-Speed Rotorcraft Concepts

P. Talbot, J. Phillips

A program of technology assessment was begun to identify the technology base required for high-speed rotorcraft (HSRC). These are vehicles that potentially combine the low-speed attributes of helicopters with the high-speed capabilities of fixed-wing aircraft (high subsonic cruise speeds of approximately 450 knots).

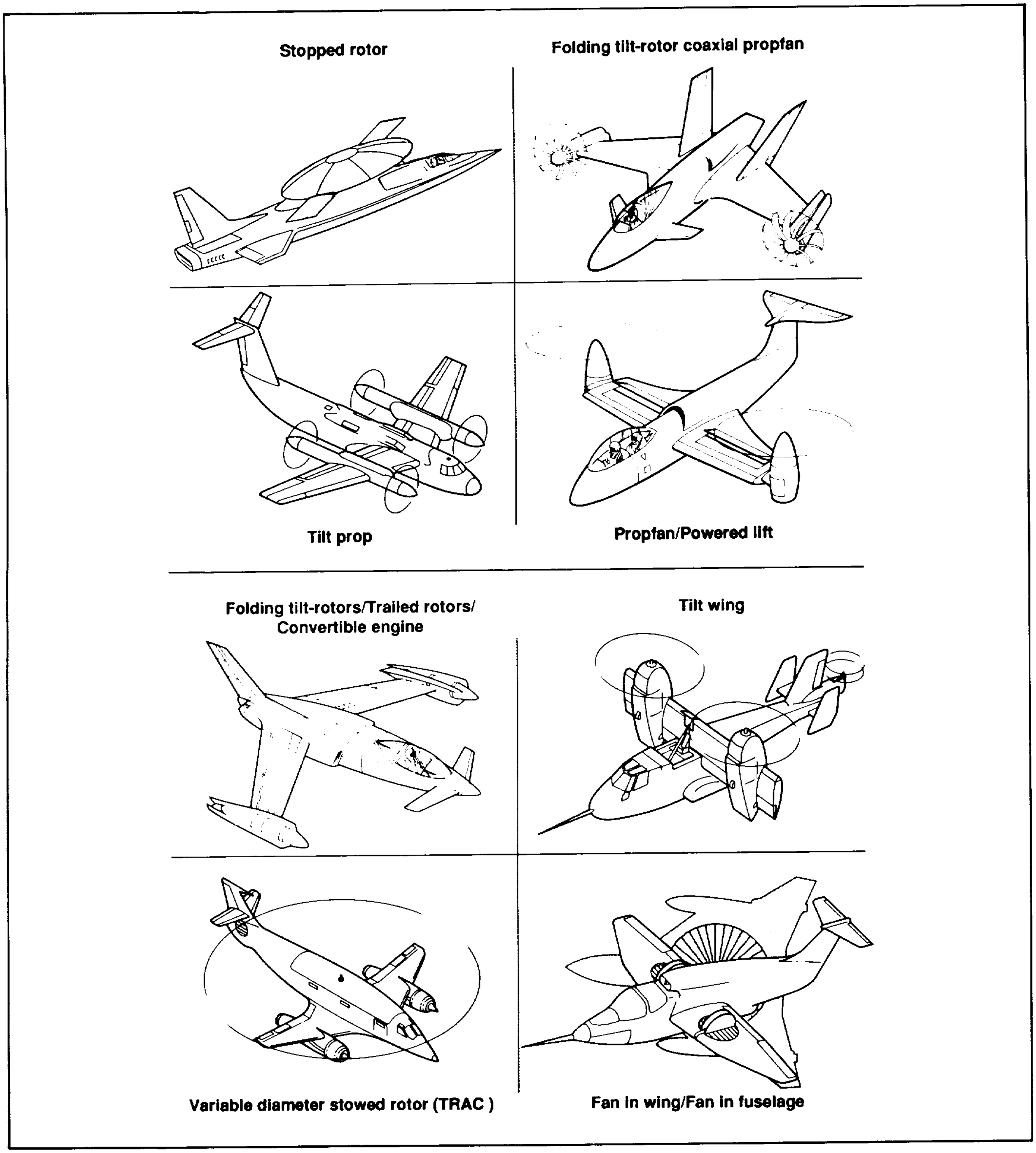
A broad range of HSRC concepts (see the figure) with the potential of meeting these performance objectives is being examined through four study contracts and an in-house systems analysis effort. The initial focus is on reducing the number of concepts to be considered so that more promising concepts can be examined in greater depth. This is being done by establishing quantitative and qualitative figures of merit against which each concept can be compared.

For the more promising configurations, mission analysis studies are being conducted to quantify the performance, weights, and propulsion characteristics needed to meet the mission requirements. Sensitivity studies of these results are intended to provide the basis for recommending which technology items are the most important to future development of these concepts and what research tasks should be undertaken to enable introduction of these concepts with acceptable risk.

In-house activities have concentrated on defining a baseline optimized conventional tilt-rotor with approximately 450-knot cruise speed and comparing it with a folding tilt-rotor which has a convertible engine. Lewis Research Center has provided various alternatives for the convertible engine and has initiated studies with Allison Gas Turbine Division of General Motors Corporation and General Electric to define weights and performance.

For a conventional tilt-rotor, a rapid increase in design gross weight has been seen as design speeds rise above 400 knots due in part to high empty-weight fractions, thick wings, and transonic effects on both rotors and wing/fuselage combinations.

Folding tilt-rotor configurations are now being studied to determine what advantages are possible due to potentially thinner wings and a propulsion system more suited to high-speed cruise flight.



High-speed rotorcraft design concepts

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UH-60A Flight Test Correlation with Analysis

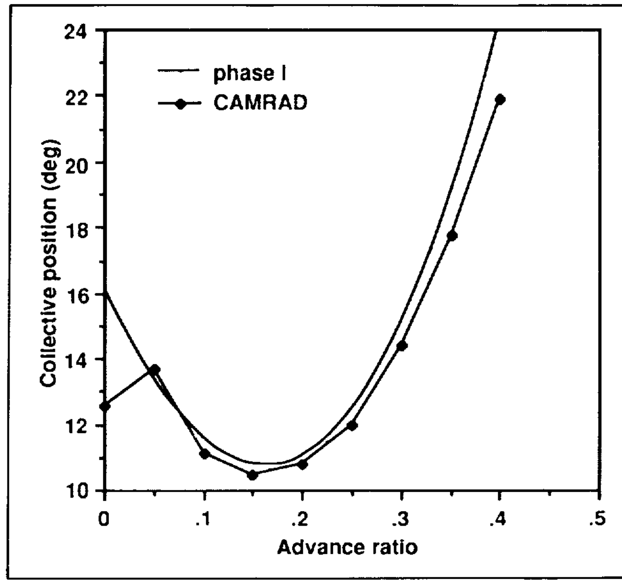
J. Totah, J. Cross

NASA, in cooperation with the U.S. Army Aviation Systems Command (AVSCOM), is engaged in the Modern Technology Rotors (MTR) Program to provide and validate the technology and methodology required to improve the performance, dynamics, acoustics, handling qualities, and cost of civil and military rotorcraft. A portion of the MTR Program consists of ground-based and flight research of the UH-60A Black Hawk helicopter, performed in four separate phases. Phase I, the Modern Rotor Aerodynamic Limits Survey, was completed with the cooperation of the Aviation Engineering Flight Activity at Edwards Air Force Base.

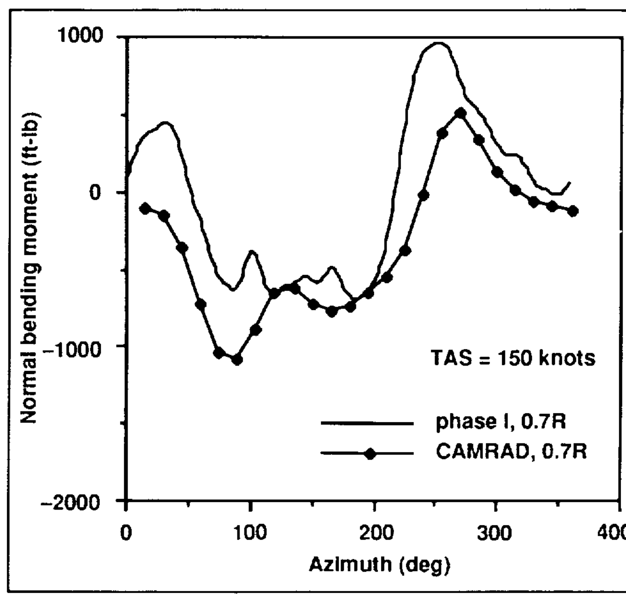
A key element of the MTR Program is the use of Phase I data to study the ability of analytical models in predicting rotor blade structural loads, rotor performance, push rod loads, and control positions. The Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics (CAMRAD) and CAMRAD/JA (the Johnson Aeronautics version of CAMRAD) are the primary analytical computer models that have been used for such studies with Phase I flight test data.

The ultimate goals in using these analytical models to predict rotor loads and performance are to determine strengths and weaknesses of the models and to determine their suitability in evaluating state-of-the-art rotor systems, such as characterized by the highly twisted, swept-tip UH-60A rotors. The study of structural blade loads, in particular, is directly important to the rotorcraft community in the design, development, and testing processes.

Recent results of a correlative study between UH-60A Phase I flight test data and CAMRAD/JA have been obtained. The study scrutinized 17 parameters which define the trim state of the rotors and the fuselage of the UH-60A at flight conditions varying from hover to 170 knots. Actual UH-60A Phase I flight test data used for correlation were obtained from the Tilt-Rotor Engineering Database System, an interactive, on-line operating system which allows near instantaneous access to flight data for a variety of research and development activities. Examples of the results of this particular correlative study are depicted in the figures.



Comparison of predicted and measured collective position versus advance ratio



Comparison of predicted and measured main rotor normal bending moment at 70% radius

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U.S./U.K. Advanced Short Takeoff and Vertical Landing Aircraft Technology Program

C. White, P. Nelms

The governments of the United States and the United Kingdom are cooperating to further the technology for a supersonic, advanced, short takeoff and vertical landing (ASTOVL) fighter aircraft. This cooperative effort (the U.S./U.K. ASTOVL Aircraft Technology program) involves the U.S. Department of Defense, NASA, the U.K. Ministry of Defense, and the U.K. Royal Aircraft Establishment. Government teams have been established to focus on the definition of a joint U.S./U.K. technology program for ASTOVL concepts. The intent of this program is to mature those concepts sufficiently to judge their relative merits and to support future program decisions, including the possibility of a flight demonstrator/research aircraft.

This ground-based technology program is covered by a Memorandum of Understanding signed by both governments in January 1986. The program focuses on a single-engine, single-seat, supersonic short takeoff and vertical landing fighter/attack aircraft with excellent transonic maneuverability and an all-weather capability. At the outset four propulsion concepts were identified as potentially feasible for this type of aircraft: (1) vectored thrust, (2) ejector augmentor, (3) remote augmented-lift system, and (4) tandem fan. The four concepts became the subject of contracted and in-house conceptual aircraft design studies in both countries.

The purpose of the conceptual design studies and associated sensitivity analyses was to provide information for use in guiding the choice of research and technology activities.

Specific objectives were

1. To investigate the general system characteristics and capabilities and thereby clarify the potential of each of the above concepts for use in future ASTOVL aircraft.
2. To identify, for the concepts, the critical technologies needed in the various discipline areas such as propulsion, aerodynamics, structures, controls and propulsion/aircraft integration.
3. To identify and assess the most promising of the ASTOVL concepts so the available resources may be concentrated accordingly.

The conceptual design studies were conducted in parallel with one detailed study of each of the four concepts being made in each country. In the United Kingdom, studies of all four concepts were conducted by a single industry team. However, in the United States, four separate industry teams conducted the four studies. Care was exercised to ensure that the design studies would provide a fair assessment of the concepts evaluated on a common basis.

In the United Kingdom, the industry team was able to standardize design input for the four concepts and, as a consequence, there was confidence that comparisons made among the four designs would not be clouded by differences in the input.

In the United States, the more complex industrial scene did not permit officials to achieve agreements on the use of common input or design practices. Thus, it was necessary for U.S. officials to conduct a normalization of designs. The U.S. normalization process involved Ames, Langley, and Lewis Research Centers as well as the U.S. Air Force Wright Research and Development Center and three U.S. Navy organizations: Naval Air Systems Command, Naval Air Development Center, and Naval Air Propulsion Center.

The normalization process included (1) removing differences in the various contractor estimation methods and assumed technology levels, (2) eliminating obvious engineering deficiencies, and (3) using common aircraft synthesis design rules/codes. Technical discipline teams for propulsion, aero/propulsion integration, controls, equipment, and weights provided input adjustments to an integration team. The integration team then produced "normalized" aircraft based on the contractors' original designs.

At the conclusion of the conceptual design studies and the successful normalization process, results were examined by a Joint Assessment and Ranking Team (JART) composed of officials from the two countries. The establishment of this joint, colocated team using criteria established before the assessment, resulted in a successful collaboration.

In its comparative assessment of the identified propulsive-lift concepts, the JART addressed three main areas: (1) concept capability, (2) risk and criticality, and (3) costs.

The JART assessment concluded that, given the application of necessary resources, all propulsive-lift concepts could be developed to meet the primary mission requirements and costs were not a discriminator. Therefore, risk and criticality formed the basis on which the JART was able to assess and rank the concepts.

The results of the joint assessment and ranking activity were presented to the U.S./U.K. ASTOVL Joint Working Group (JWG). The JWG then concluded that the most promising ASTOVL configurations are those which use remote lift for jet-borne flight (decoupling the location of the engine from the placement of the jet thrust nozzles) and conventional mixed-flow propulsive systems for wing-borne flight. Officials of the two nations have agreed that these concepts will receive the greatest attention in the technology development program to facilitate possible future development of ASTOVL combat aircraft.

The U.S./U.K. ASTOVL Technology Program, which will implement these findings, is being planned and implemented in both countries.

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Civil Tilt-Rotor Study

J. Zuk

The development and validation of tilt-rotor technology by Ames Research Center and other U.S. Government agencies and industry in the past two decades has placed the United States in an international leadership position in tilt-rotor aircraft. The military V-22 Osprey tilt-rotor aircraft is in full-scale development and is undergoing flight evaluation. The implication to civil aviation is significant. A fleet of civil tilt-rotor aircraft operating in a modernized National Airspace System is expected to reduce the current metropolitan air traffic congestion and to provide a viable alternative to alleviate the short-haul air transportation demands.

A completed Federal Aviation Administration/NASA/Department of Defense (FAA/NASA/DOD) study of the potential civil applications of tilt-rotor technology, including that of a civil version of the V-22, concluded that tilt-rotors could capture one-third to two-thirds of the high-density, short-haul air travel market. For the year 2000, a potential market greater than 1400 aircraft has been identified for a 35- to 45-seat tilt-rotor, which could be a demilitarized version of the V-22. The potential effect of this new vehicle type with new operational requirements prompted the FAA to establish a set of goals for vertiport development and certification, air traffic control modernization, and readiness for tilt-rotor demonstrations and certification.

The FAA/NASA/DOD Civil Tilt-Rotor Applications Study identified areas which, after review, need further data, development, and/or better definition to understand the tilt-rotor transport as a viable commercial vehicle. These areas include further refinement of the market requirements; a re-evaluation of the size of the market, the cost to build, and the impact on the economic viability of the tilt-rotor concept; further definition of the changes required to optimize commercialization of the tilt-rotor concept; a technical benefit/cost analysis to identify highest priority research; an operational analysis using simulators to develop certification and design criteria guidance; and a comprehensive technology plan for flight validation of the commercial concept.

The technology benefits assessment will determine the best direction for technology research. Areas addressed include better thrust/weight engine performance, alternate means of providing emergency power for one-engine-inoperative operation, lower download on wing, vibration reduction alternates, noise reduction alternates, lower drag configurations, pressurized composite fuselage, and configurations utilizing more than two engines.

Boeing (commercial aircraft), Renton, Washington, was awarded the study and the results will be available in 1990.

Intermodal transportation center

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Aviation Technology Applicable for Developing Countries

J. Zuk, L. Alton

Analysis of aviation technologies useful for formulating aviation or development plans to the year 2000 for the emerging countries of the world has been completed. The Caribbean Basin was used as a specific application.

Aviation technology was organized in the following categories: current technology in the region, applicable technology used in other regions, significant trends in technology, and technology issues regarding developing regions. Categories covered under the "Significant trends in technology" section were next generation conventional takeoff and landing (CTOL) aircraft, general-aviation aircraft, rotorcraft applications, rotorcraft technology, lighter than air, used aircraft upgrading, and computer/satellite advances.

The rapid growth of aviation technology and passenger and cargo traffic that has occurred in the past is projected to continue. These aviation technologies and transportation growth, if planned for and properly used in developing regions, offer the possibility of "leap frogging" current technology to arrive in the 21st century and bypassing many of the major costs involved in present technology (such as extensive air traffic control ground infrastructure; new and extended airports; and road, rail, port, and communication systems in remote areas).

The next generation CTOL transport aircraft, with improved infrastructure and management methods, will provide lower cost air transportation to the region from the United States and the rest of the world. The new short-haul air-transportation capability, if looked at from an overall systems and intermodal viewpoint, can offer many unique economic development opportunities. In Puerto Rico, for instance, shipment to and from remote plants to develop underused labor sources; tourism to remote attractions; and high-value, perishable produce and ornamental flowers are being proposed for a demonstration program. Satellite technology will enable rapid, economical capabilities in many areas such as navigation, communications, weather forecasting, training, and maintenance assistance.

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Three-Dimensional Viscous Rotor Flow Calculations Using Boundary-Layer Equations

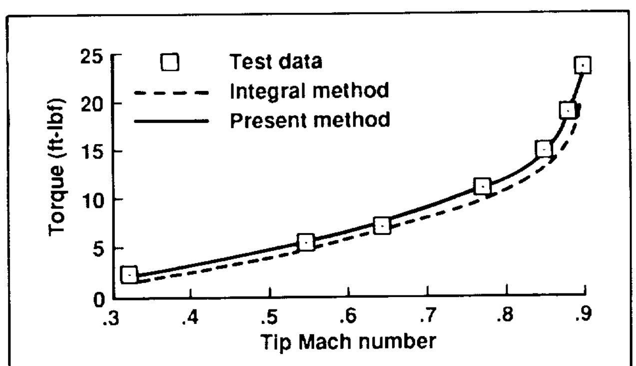
C. Chen

The ability to accurately predict drag force for rotating blades is extremely important in rotorcraft design. Currently, the most widely used method for rotor blade drag prediction incorporates two-dimensional airfoil tables to extrapolate the drag force on the blade. This method does not take the Reynolds number or the rotational effects of the blade into account, which raises doubts about the accuracy of the results. To address this problem, a new three-dimensional, viscous-inviscid interaction analysis was developed, which can predict the drag force of rotors in hover and forward flight at subsonic and transonic tip speeds.

The new analysis solves the three-dimensional boundary-layer equations in the rotating reference frame. The boundary-layer method is coupled with a full-potential method, which solves the full-potential equations in the rotating frame for rotor flows. The full-potential method provides the pressure distribution on the blade surface as the forcing function to the boundary-layer method. The boundary-layer method feeds the displacement thickness on the blade surface back to the full-potential method as a correction due to the viscous effect. This process is repeated until the solution converges. The viscous drag can thus be calculated directly to include the variations in Reynolds number and the rotational effects of the blade.

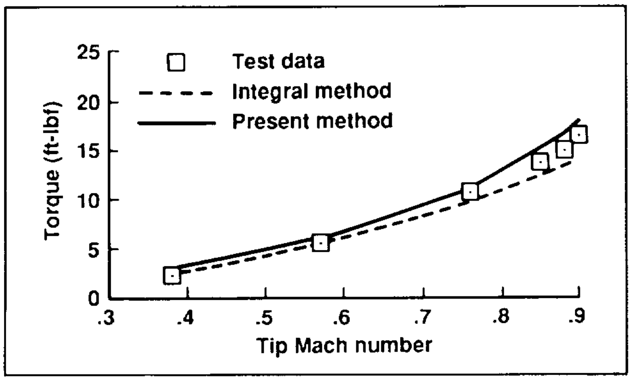
Accuracy of the analysis was first evaluated by simulating flows over a flat plate and two-dimensional airfoils. The comparison between theoretical results and experimental data showed good accuracy of the numerical procedure. The interaction analysis was then used to calculate nonlifting model rotor flows in hover and forward flight.

The first figure shows data for a two-bladed hovering rotor with rectangular blades. Data in the figure compare the torques predicted by this analysis with predictions by an integral-inviscid interaction method and with experimental data. Agreement is quite good.



Comparison of computed torques with test data for the hovering rotor with rectangular blades

The second figure shows a similar comparison for a two-bladed rotor with swept-tip blades. Agreement is good in the lower tip Mach number region (the practical application range), but less good in the high tip Mach number region.



Comparison of computed torques with test data for the hovering rotor with swept-tip blades

To validate the analysis in forward flight, comparisons of calculated blade surface pressures with experimental data were made. Agreement was again quite favorable. These comparisons demonstrate that the present analysis is able to make accurate rotor performance predictions efficiently for general rotor configurations.

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Large-Scale Wind Tunnel Studies of E-7A Ejector-Lift STOVL Aircraft

M. Dudley

There is an interest in high-performance fighter-type aircraft with short takeoff and vertical landing (STOVL) capability, because of their flexibility in basing options and their potential for enhanced maneuver capability. Although the advantages of a STOVL-capable aircraft have long been recognized, technology deficiencies limited the development of a practical design. Design areas causing the most difficulty are the requirement for a sufficient thrust-to-weight ratio for controlled hover, weight penalties for increased nozzle complexity, efficient integration of duct systems to minimize internal volume, and minimizing adverse environmental effects during ground hover.

In recent years advances in propulsion technology, innovative designs, and a better understanding of powered lift aerodynamics have reduced or closed the technology gap in most of these areas. The 40- by 80-Foot and 80- by 120-Foot Wind Tunnel investigations of the E-7A STOVL fighter demonstrate at full scale the state of these technologies, integrated into a realistic aircraft configuration.

The E-7A is a single-engine, lifting ejector/thrust deflecting STOVL aircraft fighter. It is an Ames Research Center and deHavilland Division of Boeing Aircraft modification to a General Dynamics design. It employs a lifting ejector system in hovering flight both to reduce jet temperatures and pressures under the forward portion of the aircraft and to augment the available hover jet lift. The use of lifting ejector technology is one of several promising approaches NASA is pursuing as a means of developing an advanced STOVL aircraft. The wind tunnel model used for this investigation (shown in the first figure) was funded by NASA; the Canadian Government's Department of Industry, Science and Technology; and the U.S. Defense Advanced Research Projects Agency.

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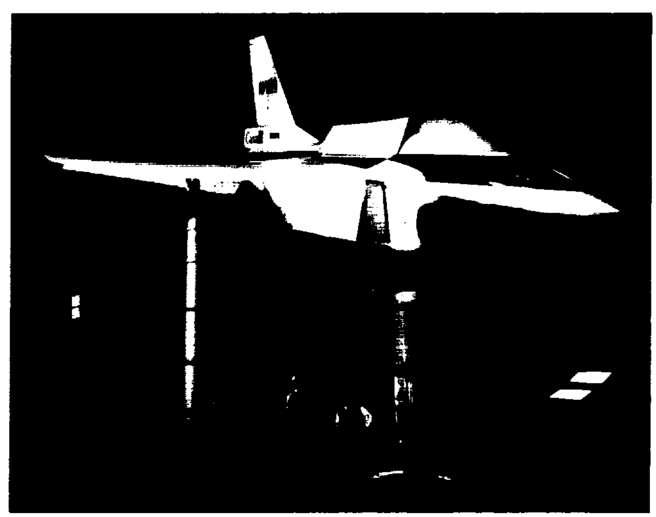
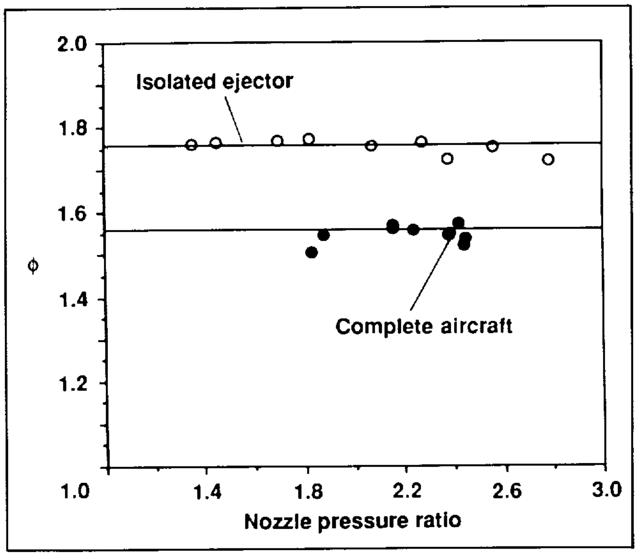


E-7A wind tunnel model

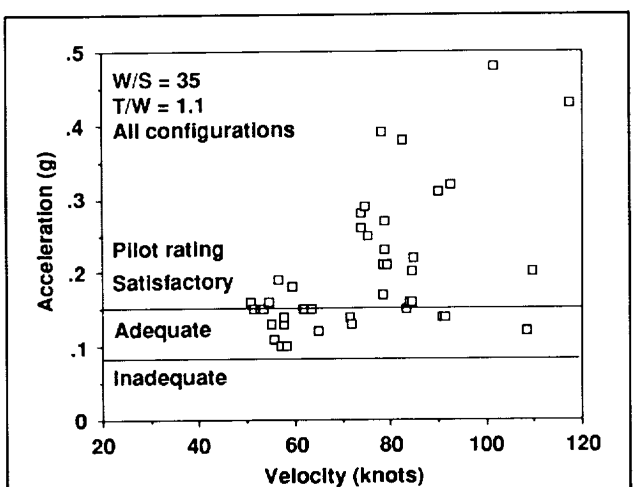
The wind tunnel investigations focused on the critical issues of hover performance and transition from jet-borne to wing-borne flight. The measured ejector augmentation, ϕ (defined as the ratio of ejector vertical lift to its primary nozzle thrust), in isolation and integrated into the aircraft, shows that there are significant installation effects, but the performance is still adequate for proposed hover operations (see the second figure).

The third figure illustrates the accelerating capability of the E-7A from jet-borne to wing-borne flight. A concern with ejector STOVL design is the effect of the ejector inlet momentum drag on the acceleration capability in transition. STOVL aircraft flight simulations conducted at Ames indicate a minimum requirement of 0.15 g positive axial acceleration in level flight throughout accelerating transition for a satisfactory pilot rating, and 0.08 g for an adequate rating.

The full-scale data for a variety of trimmed transition operating modes (ventral nozzle deflections, full and partial ejector deployments) indicate that the vehicle will have good accelerating characteristics and satisfactory pilot ratings over a wide range of configurations.



E-7A ejector augmentation



E-7A horizontal accelerating capability

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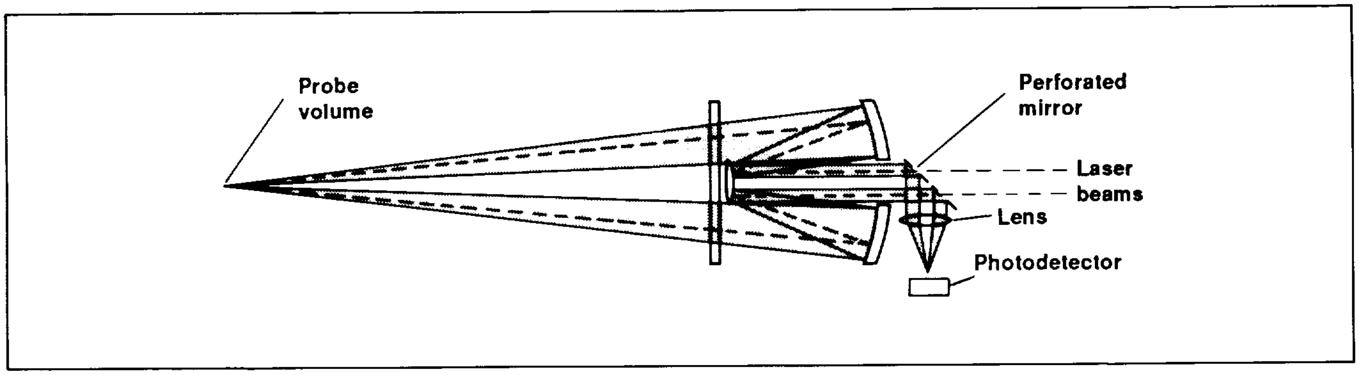
Telescope Optics for Laser Velocimetry

S. Dunagan

Laser velocimetry (LV) has become an accepted method for measuring of a velocity field without disrupting the flow with a physical probe. Optical elements are required in assembling LV instruments to perform two important functions. First, two parallel laser beams must be focused to an intersection. Interference phenomena will cause a fringe field to form within this intersection region. Particles entrained in the fluid will be periodically illuminated as they are convected through this fringe field. The second optical task is to collect the light scattered from these particles and focus it to a photodetector. The periodic electrical output from the photodetector may then be analyzed to determine its frequency content and thereby infer the velocity of the fluid.

Lens optics are generally used to perform these functions. However, residual aberrations present in lens systems as well as the high cost of custom lens design and fabrication can be problematic, particularly for large aperture applications. Schmidt-Cassegrain telescope optics provide an attractive



Schmidt-Cassegrain telescope modified for confocal backscatter laser velocimetry operation

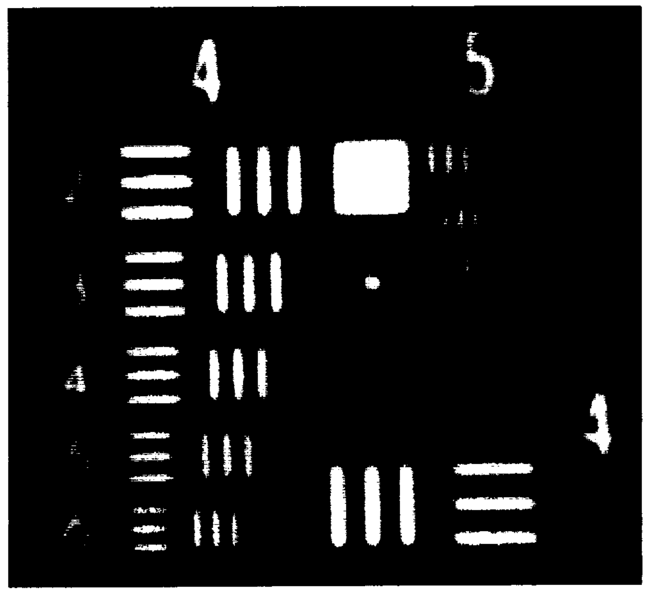
alternative to lenses. They provide very low aberration, are relatively insensitive to color variations, have built-in focusing flexibility, and are very inexpensive compared to lens optics of similar aperture. However, these optics are designed to image astronomical objects and must be modified to operate at the closer ranges required for LV.

Schmidt-Cassegrain telescope systems have been analyzed to determine if they may be adapted to LV applications. Ray tracing and Gaussian beam propagation theory have been applied in the analysis. Two simple modification approaches have been identified. The first approach involves the repositioning of the primary and secondary mirrors of the telescope. The second approach requires the repositioning of the primary mirror and the replacement of the secondary mirror. The exact positions (or curvature) required are a function of the final f-number desired for the optical system. These modifications provide very low aberration and are relatively insensitive to color variation. Telescopes may be modified to perform both the laser beam focusing and scattered-light collection functions.

The first figure shows a telescope that has been modified to perform both tasks simultaneously. This would be described as a "confocal backscatter" LV configuration.

The analysis described above has been applied in the modification of a 200-millimeter aperture Schmidt-Cassegrain telescope. The telescope has been modified to act as a beam-focusing optic or as a scattered-light collector at an operating range of 2 meters.

The second figure shows an image of a resolution target photographed through the collector. The marginally resolved bar rulings had a spacing of 7 micrometers, a value very near the theoretical (diffraction) limit.



Resolution test target photographed through modified telescope collector at 2-meter range

These results confirm the low aberration performance of these modified telescope optics for the laser beam focusing and scattered-light collection tasks of LV. For large aperture applications, a modified Schmidt-Cassegrain telescope system is an attractive alternative to a custom-designed lens optic.

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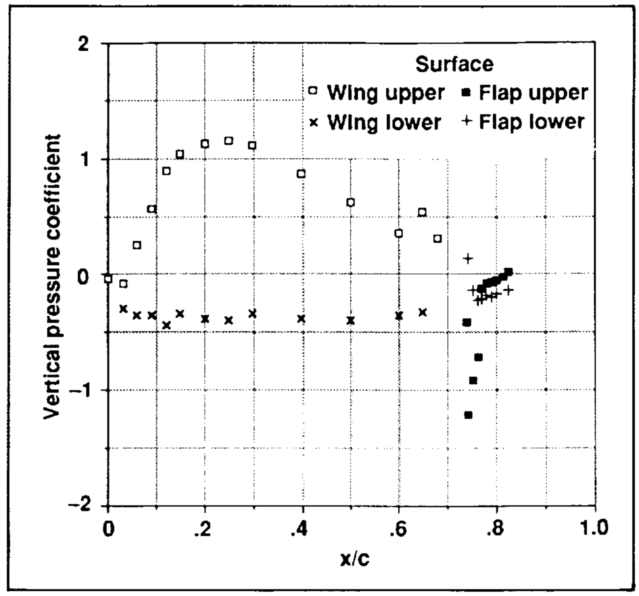
Hover Test of a 0.658-Scale V-22 Rotor and Wing in the 40- by 80-Foot Wind Tunnel

F. Felker, R. Heffernan

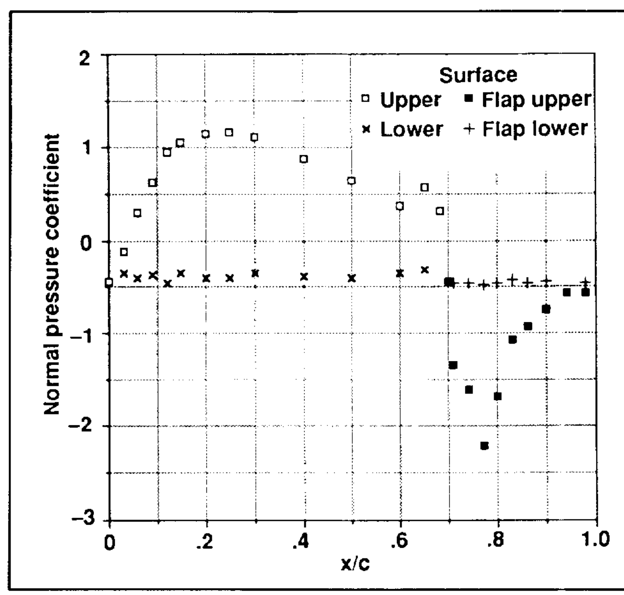
In hover, the wing of a tilt-rotor aircraft is immersed in the wake of the rotors. The downwash from the rotors impacting on the wing causes a vertical drag force on the wing, called download. The download on a tilt-rotor wing can be as large as 10-15% of the total rotor thrust. The download is a penalty associated with the tilt-rotor configuration that causes a substantial reduction in the vehicle payload. For example, if the payload is 25% of the aircraft gross weight, and the download is 10% of the rotor thrust, then elimination of the download would result in a 40% increase in the payload. Clearly, it is very important to minimize the download to achieve good hover performance with a tilt-rotor aircraft.

A hover test of a 0.658-scale V-22 rotor and wing was conducted in the 40- by 80-Foot Wind Tunnel at Ames Research Center. The principal objective of the test was to measure the surface pressures and the total download on a large-scale V-22 wing in hover. The test configuration consisted of a single rotor and semispan wing on independent balance systems. The wing was positioned in the wake of a 0.658-scale V-22 rotor, and the position and orientation of the rotor relative to the wing was selected to match the V-22 aircraft. Since only one rotor was available, a large image plane was used to represent the plane-of-symmetry of the aircraft and the effects of the other rotor and wing. Wing flap angles ranging from 45 to 90° were examined. Also, data were acquired for both directions of the rotor rotation relative to the wing, by testing both a right wing and a left wing with the same rotor.

Representative plots of the wing chordwise pressure distributions are presented in the figures. The two plots provide a comparison between two different methods of plotting surface pressures. The first figure shows the vertical pressure coefficients, which are the pressure coefficients resolved into the rotor shaft axis, while the second figure simply plots the measured chordwise pressure coefficients normal to the wing surface. Plotting just the vertical component provides a more accurate picture of which regions of the wing actually contribute to the wing download.



Wing surface pressure distribution resolved to vertical direction



Wing surface pressure distribution normal to wing surface

Results from this study, including steady and unsteady wing surface pressures, total wing forces, and rotor performance data for the many configurations that were tested, will be available as a NASA report.

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Application of the Joined Wing to Tilt-Rotor Aircraft

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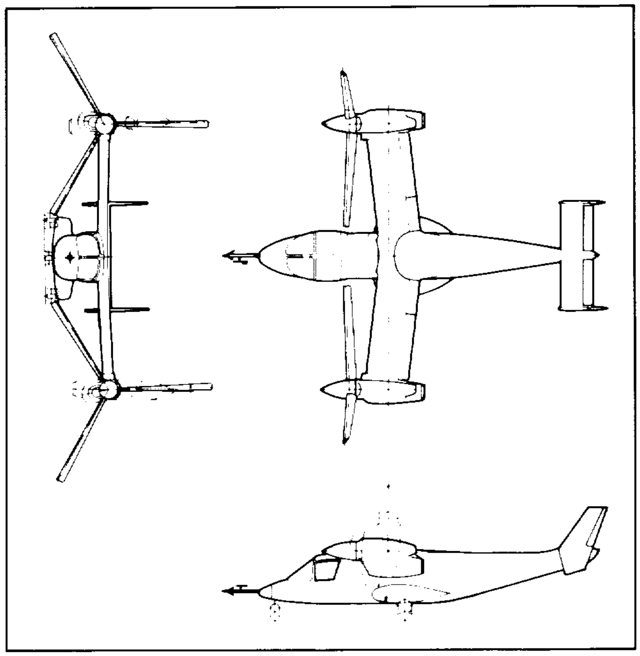
Compared to a conventional wing-plus-tail aircraft, a joined-wing configuration (with the same span and total area, made from the same material, and carrying the same load) can be significantly lighter and stiffer, can be suitable for thinner airfoils, and can have a higher span-efficiency factor.

The feasibility of applying the joined-wing concept to tilt rotors was recently examined by ACA Industries, Inc., under a contract with Ames Research Center. The problems with conventional tilt-rotor technology that this study attempted to address included the necessity of employing thick airfoils to handle the heavy rotors, aeroelastic wing/rotor coupling, hover thrust losses due to download, and rotor-wing interference in cruise.

This study was conducted to determine the possible speed improvements and other benefits resulting from the application of the joined-wing concept to tilt-rotor aircraft. The XV-15 aircraft was used as a baseline, and a corresponding joined-wing tilt-rotor was formed by replacing the cantilever wing with a joined-wing pair.

The figure shows the resulting joined-wing configuration. This consists of a forward wing in approximately the same position as the conventional wing, and an aft wing swept forward and up to meet the forward wing at the tip. This configuration is intended to provide static load capability equivalent to the conventional wing.

The baseline XV-15 cantilever wing has a 23% thickness/chord ratio. The joined-wing pair of the same span and total area, shown in the figure, was



Joined-wing tilt-rotor configuration

designed with only 12% thickness/chord ratio. As a result of the reduced thickness/chord ratio, the joined wing increased the limiting Mach number of the aircraft from M = 0.575 to M = 0.75. This translated to a potential overall increase in maximum speed of more than 100 knots. In addition to this benefit, the joined-wing configuration studied was lighter than the cantilever wing, and had approximately 11% less wing drag in cruise flight.

On the down side, the joined-wing configuration yielded a significantly lower flutter speed than the conventional wing (245 knots vs. 335 knots). This aeroelastic stability limit precluded taking advantage of the benefits described above. Although several modifications of the wing geometry and nacelle mass distribution were investigated, none produced a flutter speed above 260 knots. The study concluded that a more complete understanding of the mechanism of rotor/joined-wing coupling is required to exploit the other improvements afforded by the joined-wing concept.

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Vibration Analysis of the SA349/2 Helicopter

R. Heffernan

The ability to calculate fuselage vibration is a major consideration in the design and development of helicopters. Despite large reductions in vibration achieved through improved helicopter designs developed over the past 30 years, the current overall levels (approximately 0.05 to 0.1 g) remain significantly higher than those of jet aircraft (below 0.01 g). Until production helicopters can achieve comparably low vibration levels, vibration analysis will remain an important topic for rotorcraft.

Several aspects of the helicopter fuselage vibration problem were recently examined as part of a joint NASA/French Ministry of Defense program. This program, which has been under way for more than 5 years, was established to study the behavior of the SA349/2 Gazelle research helicopter through experimental and theoretical methods. Earlier studies have used the SA349/2 flight test data and comprehensive rotorcraft analyses to (1) correlate blade loads and rotor performance, (2) examine the effect of blade dynamics on blade aerodynamic loads, and (3) analyze hub loads. These studies provided insight into the quality of the flight test data, and into the capabilities of the analyses to predict rotorcraft behavior.

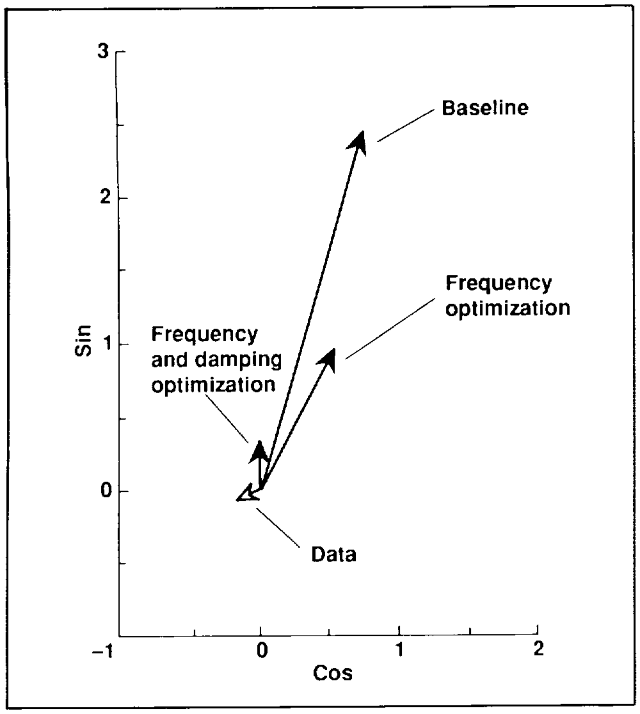
The main objectives of the most recent study were to determine current vibration prediction capabilities by comparing calculations and measurements for the SA349/2, and to gain a better understanding of how sensitive the correlations are to small changes in model parameters. To accomplish this, a forced response analysis was developed to predict acceleration at the pilot seat caused by vibrations at the rotor hub. This analysis was run using two finite element models of the airframe, an S02 model and a SAMCEF model, both of which were developed in France. The S02 model included 9 elastic fuselage modes, whereas the SAMCEF model included 14 modes, and was in general more representative of the real aircraft. Vibration calculations differed significantly depending on which airframe model was used in the analysis.

Both measured and calculated rotor hub loads were used in the forced response analysis to predict pilot seat vibration. The calculated hub loads were determined using a comprehensive rotorcraft program (CAMRAD/JA), where the influence of wake geometry, fuselage model, and coupled rotor/fuselage dynamics was examined. The most sophisticated model (i.e., CAMRAD/JA with fuselage motion feedback, a nonuniform in-flow wake geometry model, and the SAMCEF elastic fuselage model) was required to achieve the best possible correlations of rotor hub loads and fuselage vibrations. In general, hub loads correlated well in amplitude, but not in phase.

In all cases examined, vibrations predicted by the forced response program were much larger than the measured vibrations. The large overpredictions suggested that even the best finite element model (SAMCEF) required some refining to completely represent the airframe. Another possible explanation for the poor correlation was that the hub and vibration loads were not measured very accurately. This was deemed unlikely, however, because the predicted hub loads correlated fairly well with measured hub loads (at least in amplitude).

These initial correlation results led to an examination of how sensitive the vibration predictions were to changes in the SAMCEF model. In particular, minor adjustments were made to the frequency and damping of certain modes in an attempt to reduce the predicted vibration. The figure shows a vector plot of the baseline vibration predicted using the measured hub loads in the forced response program. Although the baseline vibration overpredicted the measured vibration (open arrow), changes of only a few percent in modal frequency and damping for only 3 of the 14 elastic modes resulted in huge reductions in predicted vibration. The figure shows that optimizing the frequency and damping of the SAMCEF model resulted in predicted vibration of the same magnitude as the data, although of different phase.

This study showed that minor changes in the airframe model could produce major changes in the resulting vibration; therefore, establishing an accurate finite element model is very important for predicting vibration.



Effect of varying modal characteristics on predicted pilot seat accelerations: μ = 0.370, C_T/σ = 0.66

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Bell 412 Pressure-Instrumented Main Rotor

S. Jacklin

The Rotorcraft Aeromechanics Branch at Ames Research Center has nearly completed acquisition of a highly instrumented Bell 412 main rotor blade set. The table shows the distribution of the 292 pressure transducers, 46 strain gages, and 24 accelerometers among the four blades. The branch has already conducted several aerodynamic interaction tests using a nonpressure-instrumented Bell 412 blade set, and mating hardware exists for both the rotor test apparatus (RTA) and the 576 test stand rotor test rigs owned by the branch. The acquisition of this pressure instrumented blade set will afford the opportunity to study many important aerodynamic phenomena and to provide continuity of the in-house research program by using this previously documented and well understood rotor system.

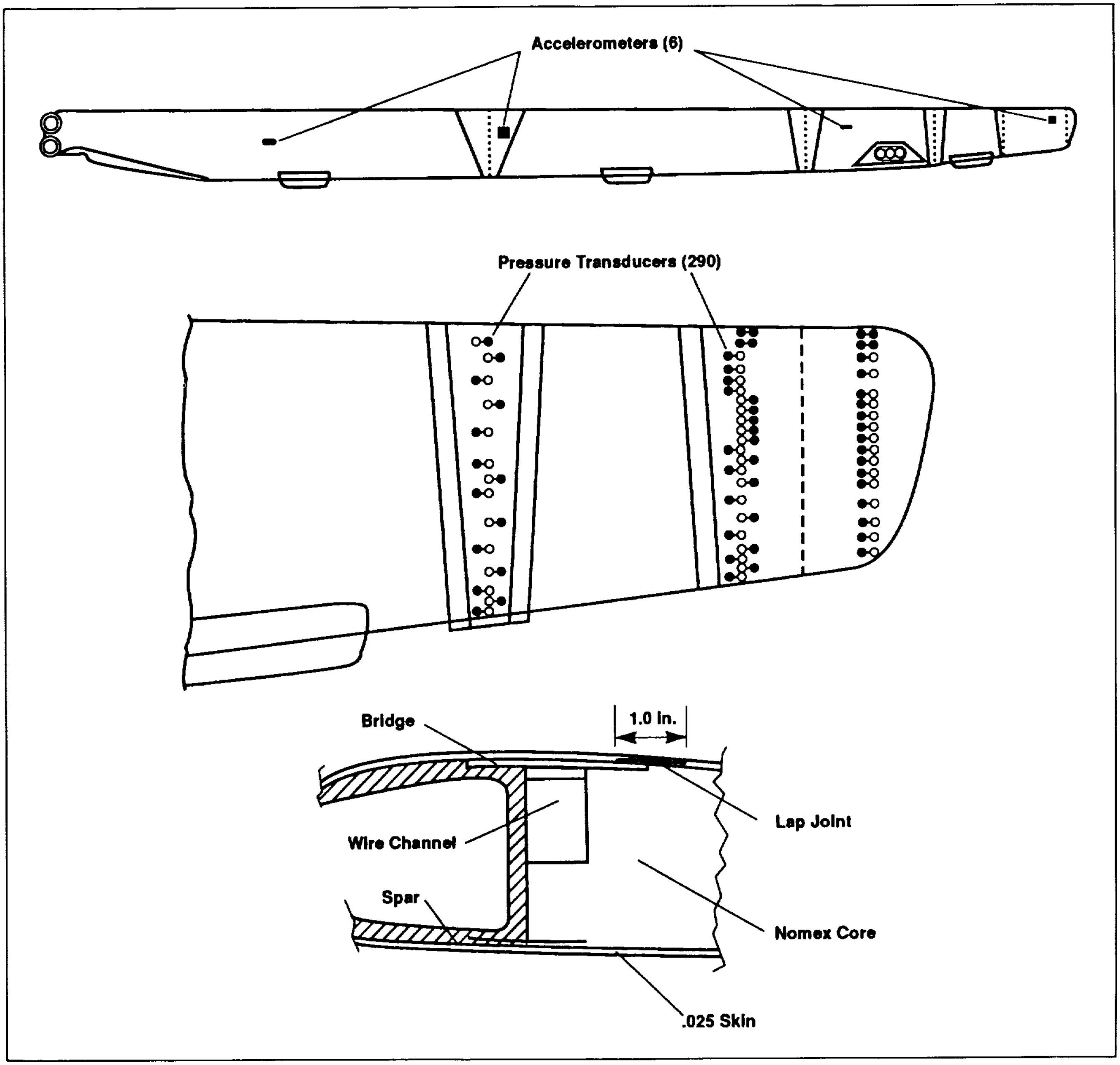
The manner of blade instrumentation is noteworthy. In an effort to minimize cost, it was decided to instrument an existing blade set. This required surface mounting of the pressure transducers and strain gages. Although the strain gages did not pose an aerodynamic problem, the many wires and 3/100-inch height of the 292 pressure transducers had the potential for corrupting the flow. To accommodate the many wires, a 0.5-inch wide, 1-inch deep trough was cut along the upper surface of the A and C blades, just behind the spar. After laying the wires in the trough, the blade surface was restored and Fiberglas belts were placed over the pressure transducers to smooth out the airflow. An analysis was performed at Ames to determine the optimal blade section contours shown in the figure. The resulting belt widths accommodated spanwise flow effects for 95% of the pressure transducers up to a 0.40 advance ratio.

This rotor will be used to study a number of interesting aerodynamic phenomena. Used with the pressure-instrumented 576 test stand and Lynx pressure-instrumented tail rotor, a full assessment of main rotor, body, and tail rotor aerodynamic interactions can be performed.

Information from the pressure, strain, and accelerometer gages will be used to gain an understanding of how the aerodynamic loading changes with the application of higher harmonic control for stability augmentation or vibration reduction. The on-blade accelerometers will also provide mode shape information and be useful in evaluating various rotor mode control concepts. Since the dynamic range of the pressure transducers is above 40 kilohertz, it will also be possible to study various acoustic phenomena, including the influence of higher harmonic control on blade vortex interaction noise.

TRANSDUCER DISTRIBUTION

Blade	Pressure Upper-Lower	Strain Flap-Chord-Torsion	Accelerometers Flap-Lag
A	99-86	2-2-2	4-2
B		2-2-2	4-2
C	57-50	9-9-10	4-2
D		2-2-2	4-2



Pressure-instrumented Bell 412 blade

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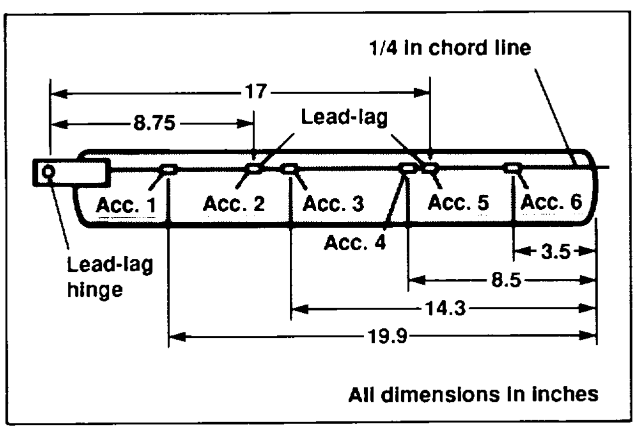
Experimental Studies in System Identification of Rotor Dynamics

S. Jacklin

A series of experiments is under way at Princeton University's Rotorcraft Dynamics Laboratory under the direction of Professor Robert McKillip, Jr., to study the applications of kinematic observer theory for rotor state parameter identification. Efforts during the past few years have indicated the benefits of using kinematic observers for helicopter parameter identification. The advantage of the kinematic observer scheme is that the state variables of the helicopter rotor can be estimated without requiring any aerodynamic modeling of the rotor flow field. The method employs blade-mounted accelerometers and provides greater algorithmic simplicity and computational robustness over traditional extended Kalman filter identification approaches.

During 1989, a 4-foot diameter, accelerometer-instrumented rotor blade set was constructed out of urethane foam. The rotor was carefully fabricated such that its first two flapping frequencies were Froude-scale representative of a real rotor. As shown in the figure, each blade incorporated six miniature accelerometers.



Accelerometer position layout in a rotor blade

Open-loop testing showed partial success in reconstruction of the blade flap and flap rate from measured flap accelerations. Problems arose when the rotor was found to be very soft in torsion. Because the observer was based on a model which neglected torsional motion, the effects of cyclic pitch and aeroelastic torsion corrupted the estimation process. Extension of the model to include torsional motion is planned.

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Generalized Kalman and Least Mean Square Filters for Multistep Identification

S. Jacklin

The system identification performance of two new stochastic methods was compared against the performance of the well-known, classical Kalman filtering technique. For many control applications, it is necessary to identify model parameters which relate the control input to the quantities to be controlled. Methods for obtaining such information are called system identification techniques.

Although off-line methods, such as the familiar least squares technique, can be used for time-invariant systems, stochastic methods are required when the parameters change with time. In that case, the more recent measurements are better indicators of the system state than a batch of measurements taken over time.

The classical Kalman filtering strategy is to use a single measurement and a wealth of user-supplied tuning information to perform the identification. Although computationally efficient, the use of only one measurement often makes the method prone to instability and convergence problems.

The generalized Kalman and generalized least mean square filters are methods which are similar to the classical Kalman filter, but allow for more than one measurement to be used in their formulation. The table illustrates that the generalization has the desirable effect of reducing the amount of user-supplied tuning information at the expense of gathering information from more measurements. This means less time needs to be spent adjusting the filter for successful implementation, since optimal tuning information is often unknown to the user, past measurements are always available.

TUNING, MEASUREMENTS, AND COMPUTATION TIMES OF CLASSICAL AND GENERALIZED METHODS

	Major tuning parameter matrices	Number of measurements used	Relative 1-step (4-step) computation times
Classical Kalman filter	3	1	2.06 (N/A)
Generalized Kalman filter	2	1 to N	2.84 (4.68)
Generalized least mean square filter	1	1 to N	1.00 (2.02)

A computer simulations study was performed to evaluate the identification performance of the two new methods against the classical Kalman filter. It was seen that to maintain similar identification accuracy, the generalized Kalman filter method required the use of four measurements and twice as much computation time as the classical Kalman filter method. Surprisingly, the generalized least mean square filter matched the identification accuracy of the classical Kalman filter method that used only one measurement, yet was computationally twice as fast. By using more than one measurement, the generalized least mean square method further improved the identification accuracy; however, it requires more computation time. It is therefore anticipated that the tuning ease and performance of the generalized methods will encourage widespread application.

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Study of Aeroelastic Problems Using Active Controls

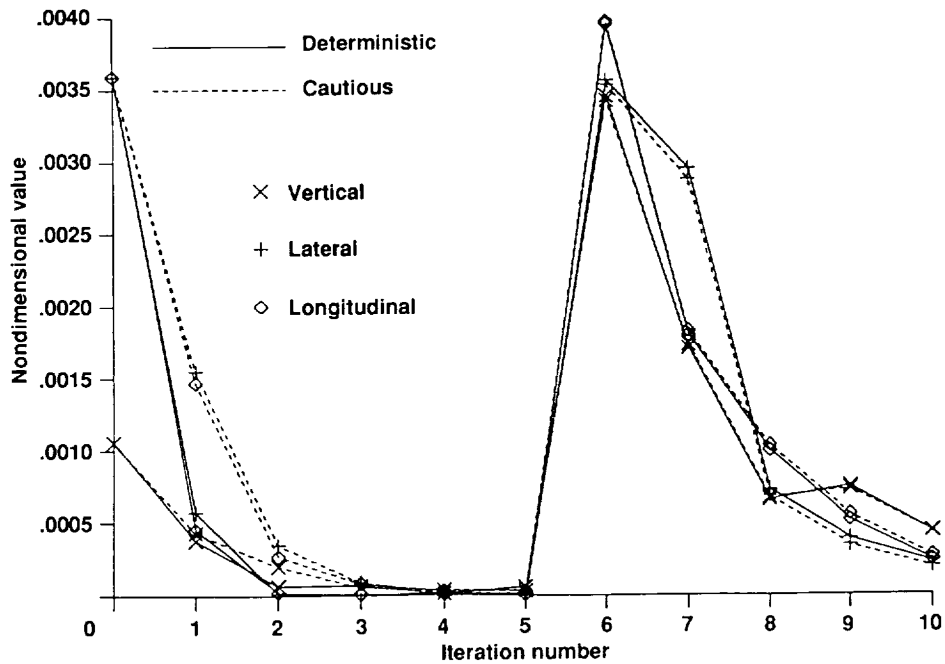
S. Jacklin

Although hingeless and bearingless rotor configurations are mechanically simpler and lighter, their development requires careful analysis to avoid undesirable active control problems. A study was conducted by Professor Peretz Friedmann and Dr. Lawson Robinson at the University of California, Los Angeles, to investigate such problems for both hingeless and articulated rotor systems. Their simulation considered a coupled flap-lag-torsional aeroelastic stability and response analysis which incorporated a time-domain, unsteady aerodynamic model. The blades were modeled using Galerkin-type finite elements combined with an implicit formulation, enabling representation of the loads in a general manner.

During 1989, a higher harmonic controller (HHC) was included into the blade model. Since the fuselage model was assumed to be rigid, the objective function of the control laws was to minimize the calculated vertical hub shears. Deterministic and cautious controllers based on local and global HHC models were implemented with different combinations of input parameters identified using a Kalman filter. The effects of unsteady aerodynamics were compared with the results obtained with quasi-steady aerodynamics in the general context of HHC simulations.

The simulation was used to clarify a number of fundamental issues associated with the practical application of HHC to realistic rotor systems. It was shown that the use of steady and quasi-steady aerodynamics led to different, but equally effective, control requirements for hub shear reduction.

As shown in the figure, deterministic and cautious controllers were equally successful in reducing hub shears for the fairly severe condition of a step change of 0.30 to 0.35 advance ratio. When using a global controller on roughly equivalent articulated and hingeless rotors, it was shown that hub shears could be reduced, but not both hub shears and hub moments. As the shears were reduced, there were large increases in hub moments and pitchlink loads for the hingeless rotor, but only moderate increases for the articulated rotor. Much larger HHC angles were required to reduce shears for the hingeless rotor. It was also indicated that application of HHC to the hingeless rotor led to an increase in required power of 1.44%, while for the articulated rotor the increase was only 0.18%. The aeroelastic stability margins of the articulated and hingeless rotors were not degraded by applying the HHC.



Iteration history of hub shears for deterministic versus cautious global control, optimization at $\mu = 0.3$, then step change from $\mu = 0.3$ to $\mu = 0.35$

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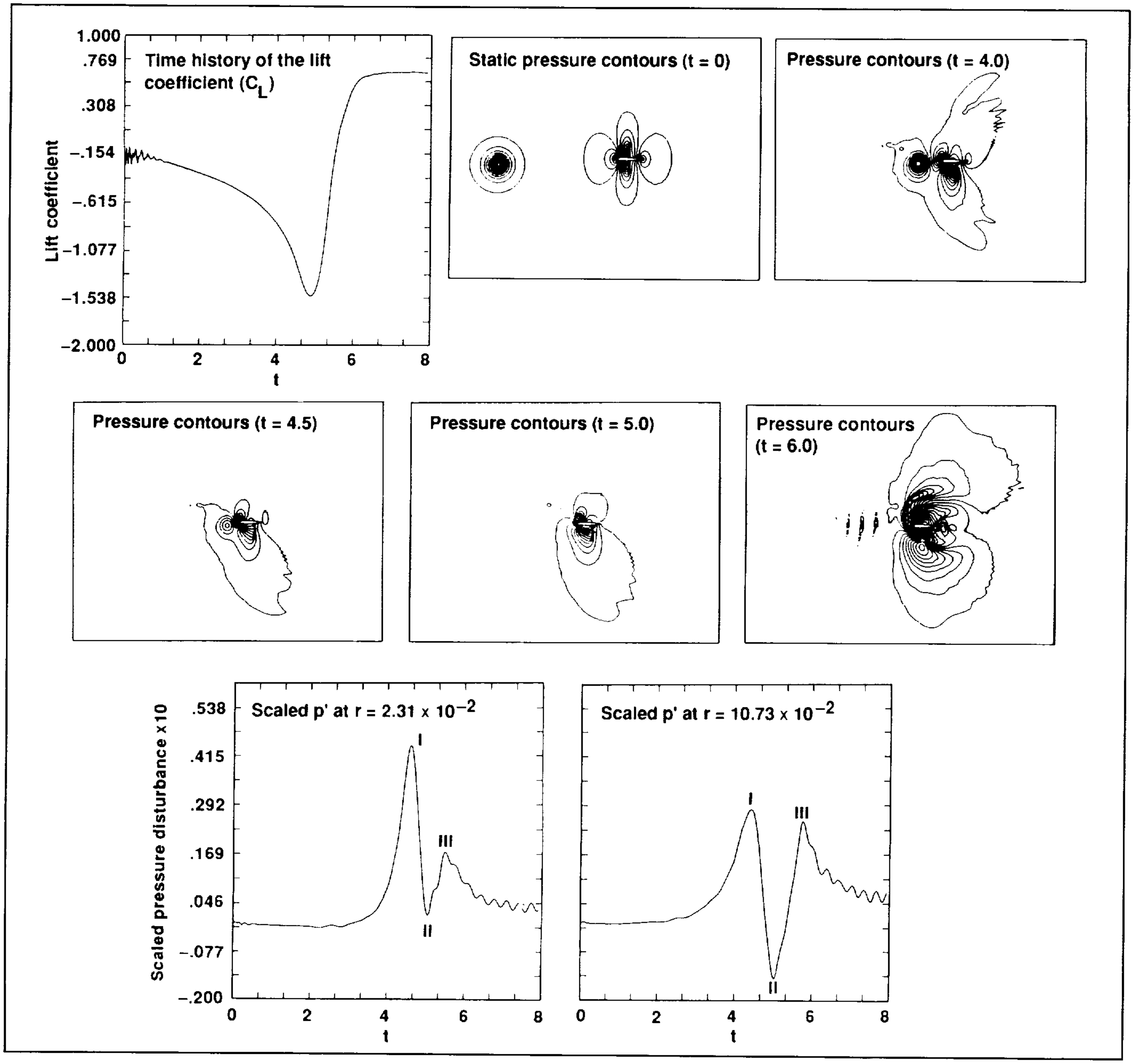
Calculation of Helicopter Rotor Blade-Vortex Interaction by Navier-Stokes Procedures

C. Kitaplioglu

Blade-vortex interaction (BVI) is a well-known phenomenon that occurs in the flow field around a helicopter rotor and is one of the primary sources of noise and vibration. BVI is a very complex, three-dimensional, unsteady phenomenon. Previous computational studies of BVI have been based on either two-dimensional, unsteady or three-dimensional, steady models. These studies have provided valuable insight into the nature and physics of the problem and have laid the groundwork for further advances. Recently, Scientific Research Associates (SRS), under contract to Ames Research Center, began one of the first efforts to compute three-dimensional, unsteady BVI at arbitrary vortex-blade intersection geometries.

The proposed solution involves the use of a Navier-Stokes code with a linearized block/alternating-direction implicit solution algorithm. The fully three-dimensional, unsteady problem is being approached in several stages, each successively more complex than the previous stage.

Several phases of the work have been completed. In the initial phase, the feasibility of using this basic approach was demonstrated by performing model three-dimensional calculations of a simple vortex interacting with an airfoil leading edge. These

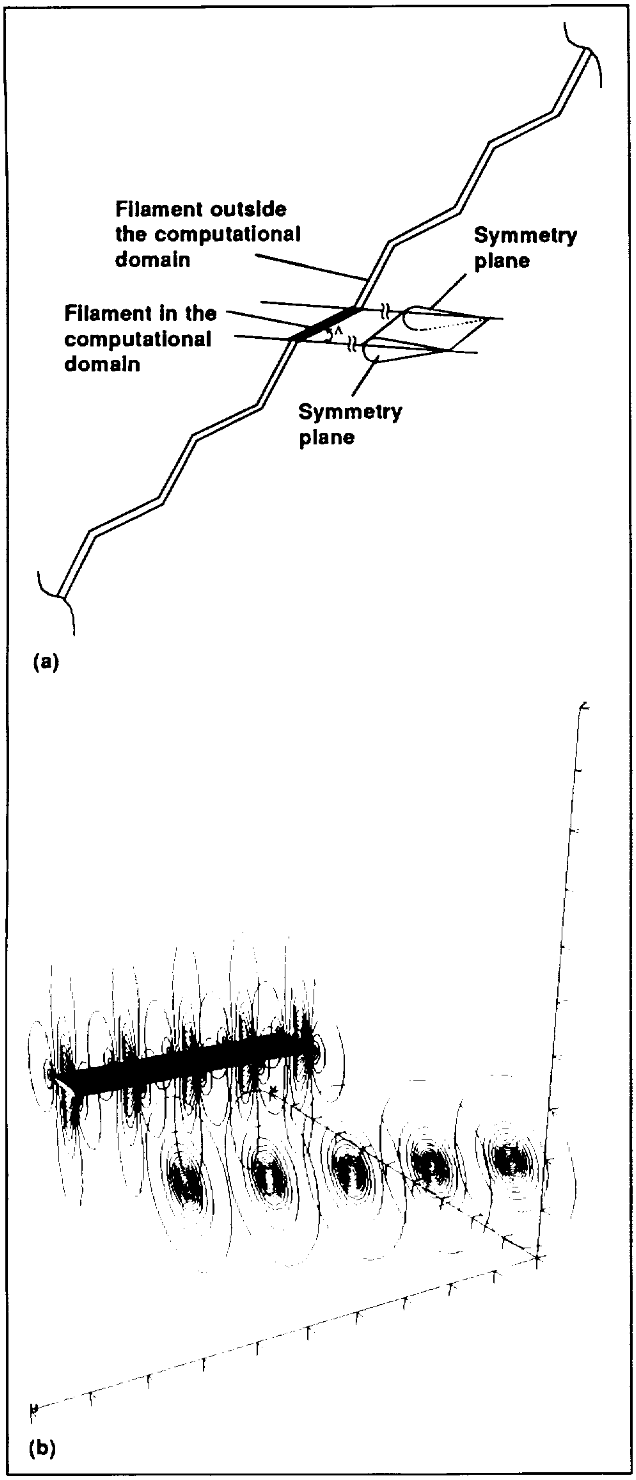


Two-dimensional results

calculations, as well as the work of previous investigators, point to the importance of correctly modeling the vortex characteristics and the boundary and initial conditions.

Therefore, during the second phase, work focused on improving the numerical scheme to reduce numerical errors in simulating vortex-dominated flows. The current scheme (which is second-order accurate in time and second-order accurate in space, and incorporates an implicit iterative procedure to reduce numerical "splitting" errors) yields a vortex as stable as the best previous models.

During 1989, two-dimensional calculations of vortex-airfoil interactions were completed. Test cases at Mach number of 0.8 and Reynolds number of 10^6 were computed. Results compared favorably with previous results, but the test cases used fewer grid points while achieving a comparable accuracy



Three-dimensional model. a) Overall geometry; b) pressure contours at initialization

level. Dominant processes during the interaction are the development of large pressure gradients near the upper leading edge and the development of disturbances at the root of the lower surface shock. High pressure pulses are emitted from the leading edge, and acoustic waves are radiated from the lower surface region originally occupied by a supersonic pocket.

During the latest phase of the work, the code is being extended to the three-dimensional case, together with appropriate extensions of the vortex and turbulence models. The computational resources of the Ames National Aerodynamic Simulator are being used to accomplish this research.

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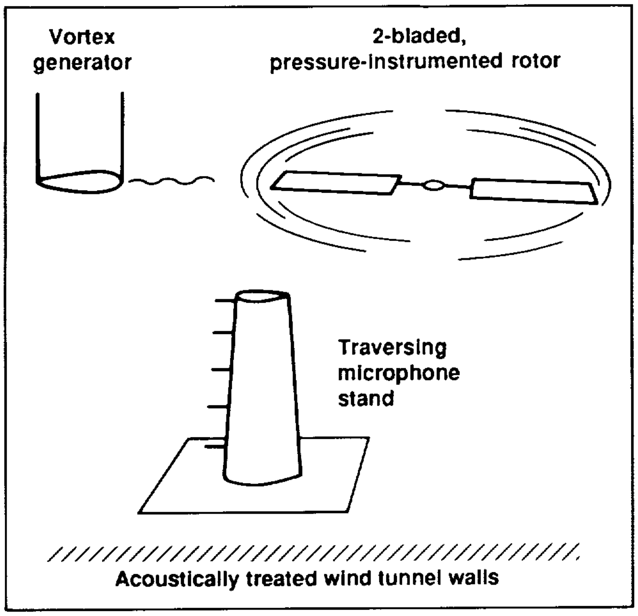
Small-Scale Study of Rotor Blade-Vortex Interaction Acoustics

C. Kitaplioglu

Considerable attention has focused during the past several years on helicopter rotor blade-vortex interactions (BVI), particularly on the resulting noise. Several computational codes have been developed and several tests were performed to gather data on this phenomenon.

The experiments of Caradonna, Strawn, and Bridgeman are of particular interest because provision was made for independent generation and control of a vortex during its interaction with a rotating blade, while the rotor itself was operated in a way that minimized the influence of its own tip vortices and wake. It was possible, in this manner, to simulate important BVI geometries and to carry out sensitivity studies. Unfortunately, these experiments did not include acoustic measurements.



Acoustically treated tunnel walls

Ames Research Center has initiated a research project to perform similar experiments, with a specific focus on acoustic measurements as well as more detailed measurements of blade surface pressure distributions. Such simultaneous measurements will yield a consistent data base that can be used to study both the aerodynamics and aeroacoustics of BVI in a systematic fashion.

A 7-foot diameter, pressure-instrumented, two-bladed rotor will be mounted in the Ames 40- by 80-Foot Wind Tunnel. A separate vortex generator will be mounted upstream of the rotor at several locations to permit variation of vortex-blade encounter parameters (e.g., vortex strength, vortex age, vortex-blade miss distance, interaction angle) and to measure the sensitivity of the rotor's aerodynamics and acoustic field to small changes in these parameters. The wind tunnel acoustic lining, as well as additional acoustic treatment, will yield a good environment for microphone measurements. A traversing streamlined microphone stand will allow acoustic measurements at narrow angular resolutions and will yield a detailed map of the acoustic field directivity associated with various BVI geometries, as well as the sensitivity of the acoustic field to small changes in BVI parameters.

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Unsteady Panel Method for Rotor/Wing Interactions

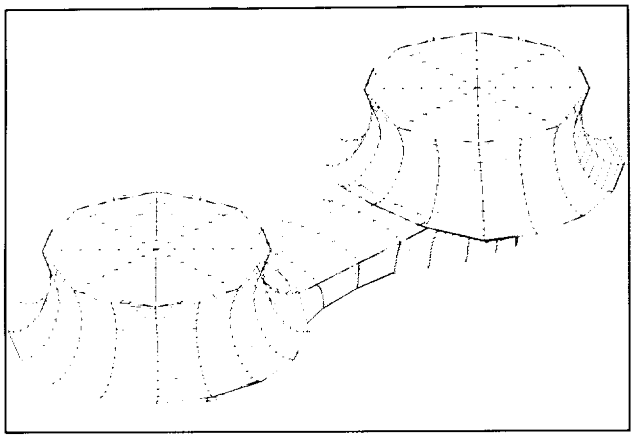
J. Lee

Aerodynamic interaction between the rotor and wing of a rotary wing aircraft in hover produces a vertical drag, often referred to as download. Download has a significant detrimental effect on payload performance. A reliable computational scheme is important for an optimal wing design to reduce download.

The flow field associated with the rotorcraft download is complex. The rotor wake concentrates in a tight tip vortex, which is three-dimensional and unsteady. With the rotor wake impinging on the wing upper surface, the flow over the wing is not only three-dimensional and unsteady, but also separated from the leading and trailing edges.

An algorithm based on a panel method is being developed for the download prediction. The flow model combines a lower-order panel method for the wing and the separated wing wake, and a curved vortex element method for the rotor and its wake. The rotor is represented by an actuator disk with known pressure jump. The method is inherently unsteady. The flow is assumed to be impulsively started, and the subsequent solution is obtained by tracking the wake panels and solving the associated flow field. Kutta conditions are applied at the specified separation points. A test run on a typical hovering tilt-rotor configuration shows the calculation is able to reproduce the general flow feature observed in flow visualization experiments, such as chordwise flow near the wing tip and spanwise flow near the wing root (see the figure).

The close interaction between the rotor tip vortex and the wing upper surface is being analyzed. A correction term is added to the induced velocity to compensate for the incompatible panel size and vortex core. Wake redistribution is also incorporated to account for the large vortex stretching near the wing surface.



Rotor/wing interaction of a hovering tilt rotor

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Comparison of Three Helicopter Vibration Controllers

J. Leyland

A comparison was made of the applicability and suitability of a deterministic controller, a cautious controller, and a dual controller for reducing helicopter vibration by using higher harmonic blade pitch control. A randomly generated linear plant model was assumed and the performance index was defined to be a quadratic output metric of this linear plant.

A computer code, designed to evaluate these controllers, was used to accomplish this comparison. The effects of random measurement noise, initial estimate of the plant matrix, and plant matrix propagation rate were determined for each of the controllers.

With few exceptions, the deterministic controller yielded the greatest vibration reduction, as characterized by the quadratic output metric, and operated with the greatest reliability. Theoretical limitations of these controllers were defined and appropriate candidate alternative methods, including one method suitable to the cockpit, were identified.

A control optimization method alternative to those employed by the aforementioned controllers was identified, and the corresponding general equations were derived. This method seeks to minimize the actual performance index (i.e., constraint penalty terms are not adjoined to the performance index) subject to the actual constraints at specified time points. Classical max/min calculus, with the constraint vector adjoined to the performance index by means of an adjoint vector composed of Lagrangian multipliers, was used to derive necessary conditions for optimality. For this formulation, the inequality constraints were transformed to the standard equality constraint function form by defining appropriate slack variables.

A stochastic controller alternative to the cautious and dual controllers was formulated. The cautious and dual controller formulations adjoin stochastic penalty terms composed of functions of covariance matrices to the performance index; whereas the alternative stochastic controller (based on the general form of the minimum variance controller) seeks to minimize the expected value of the actual performance index at specified time points, subject to the actual constraints.

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Kinematics, Constraints, and Power Study for Higher Harmonic Control

J. Leyland

An important class of techniques to reduce helicopter vibration is based on using a controller to optimally define the higher harmonic blade pitch. These techniques typically require solving a general optimization problem and the determination of a control vector, which minimizes a performance index where functions of the control vector are subject to inequality constraints.

Six constraint functions associated with swashplate blade pitch control were identified and defined in a recent study. These functions constrain: (1) blade pitch Fourier coefficients expressed in the rotating system, (2) blade pitch Fourier coefficients expressed in the nonrotating system, (3) stroke of the individual actuators expressed in the nonrotating system, (4) blade pitch expressed as a function of blade azimuth and actuator stroke, (5) time rate-of-change of the aforementioned parameters, and (6) required actuator power.

These inequality constraint functions, when transformed to equality constraint functions via slack variables, have the standard form required for classical max/min calculus minimization problems where the constraint vector is adjoined to the performance index by means of an adjoint vector composed of Lagrangian multipliers.

The associated kinematics of swashplate blade pitch control by means of the strokes of the individual actuators was derived to define the aforementioned constraints. The form of the power relationship to the individual actuator strokes contains a constant, the first and second harmonic terms, and the (N-2), (N-1), N, (N+1), (N+2), (2N-2), (2N-1), 2N, (2N+1), and (2N+2) harmonic terms where N is the number of blades in the rotor.

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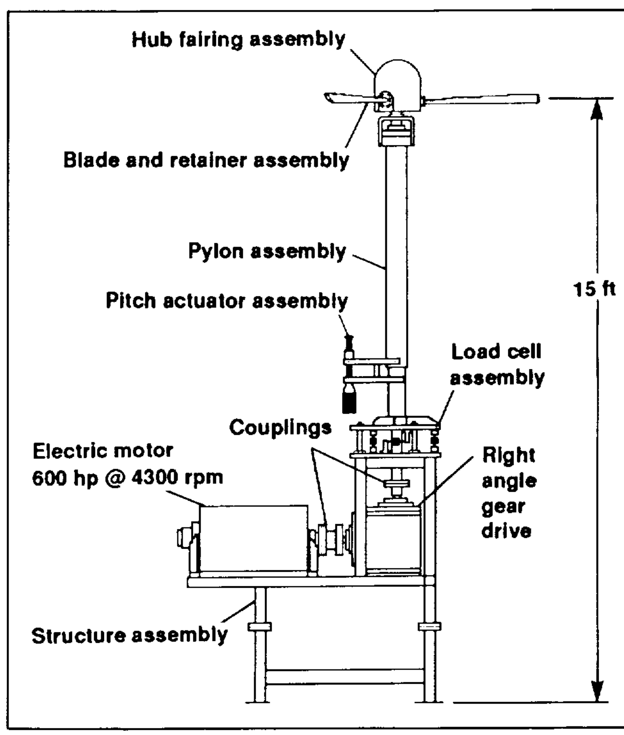
Hover Test Rig Development

J. Light

A small-scale Hover Test Rig (HTR) was recently developed for use in hover testing of model helicopter rotors. This new test rig fills a significant gap in the testing capabilities at Ames Research Center, allowing small-scale rotor testing at high thrust conditions (2100 pounds) and tip speeds up to 2867 revolutions per minute.

The rig was designed to be simple to operate while still being versatile. It has no lead/lag or flapping hinges, and the only controls available are blade collective pitch and rotor revolutions per minute. However, the rotor can thrust either up or down, and the shaft can rotate either clockwise or counterclockwise. With some modifications, the test rig can accommodate two-, three-, or four-bladed rotors.

The figure shows the major components of the HTR. The thrust and torque of the rotor are measured through the load cell balance and the instrumented coupling between the rotor shaft and gear



Hover test rig

drive. A 600-horsepower motor powers the rotor. Because of the robust design of the test rig, limitations in the size of the rotor are essentially determined by the centrifugal loads on the hub.

The first planned use of the test rig is in a V-22 hover/download test. Small (0.18-scale) wooden V-22 blades were built for this test. The test will examine V-22 hover performance, tip vortex geometry, and wing download. The download portion of the test will examine: (1) the effect of upper surface blowing on download reduction, and (2) the effect of rotor rotation direction and rotor/wing geometry variations on a model V-22 wing.

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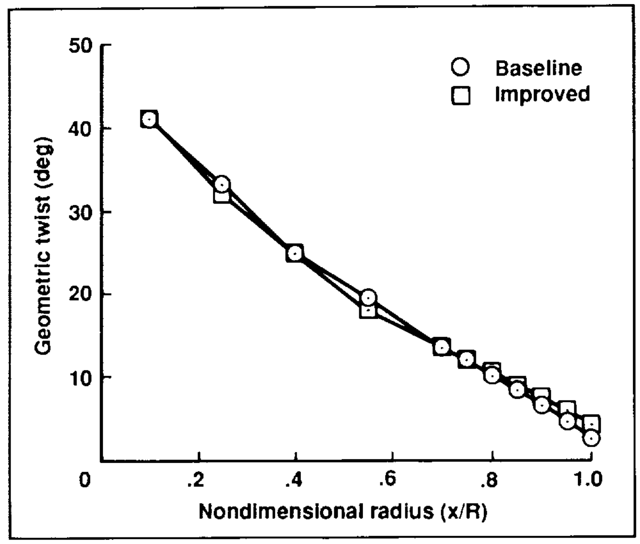


Baseline and improved twist distribution for the advanced technology blade rotor at thrust coefficient 0.0118

Rotor Blade Optimization in Hover

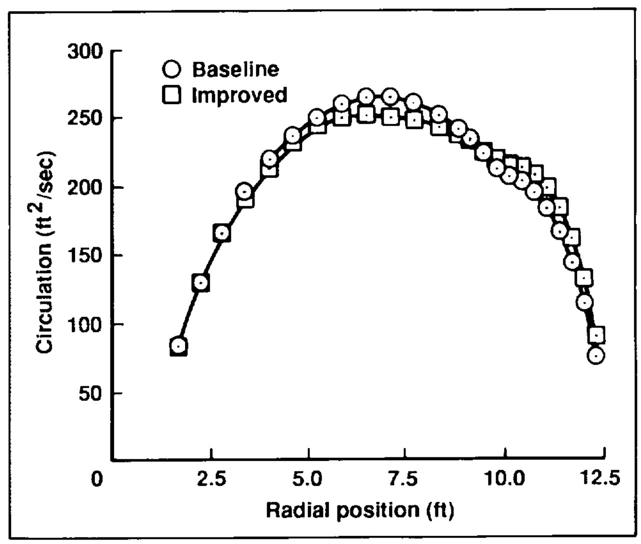
J. Light

An analytical method for improving the hover performance of a helicopter was developed by Continuum Dynamics, Inc. (CDI) under a contract with Ames Research Center. This Phase I Small Business Innovative Research (SBIR) contract uses a linear optimization scheme to minimize the power required for a constant thrust.

The method is based on a free-wake hover analysis using curved vortex wake elements, a lifting surface blade representation, and an efficient wake relaxation scheme. The blade twist distribution was the only variable used in the optimization process.

A sample case was computed for the square-tip variant of the advanced technology blade (ATB)/ XV-15 main rotor. A relatively simple wake model (4 free filaments) was used for this example. Ten optimization loops changed the twist distribution as shown in the first figure.

This change in the twist distribution essentially flattened the circulation distribution along the blade as shown in the second figure. These changes resulted in an increase in the figure of merit from 0.797 to 0.818 at a thrust coefficient of 0.0118. This increase in hover efficiency is significant because the ATB/XV-15 rotor is already very efficient in



Baseline and improved bound circulation distribution for the advanced technology blade rotor at thrust coefficient 0.0118

hover, and also because only one variable was changed to achieve the increase. Greater improvements in efficiency were obtained when simple two- and four-bladed rotors were used as the baseline cases.

A Phase II SBIR contract has been awarded to continue the work. The optimization scheme will be improved by adding design variables such as tip sweep, anhedral, and chord distribution; examining nonlinear optimization techniques; and using the optimization technique to aid in wake convergence. Several other upgrades will be made to the analysis to increase its usefulness as a design tool. These include refining the current lifting surface blade analysis, including a finite element structural model, implementing a refined wake in the tip region, and improving calculation of blade/vortex events. Completion of this work will provide helicopter designers with an important tool for improving helicopter hover performance.

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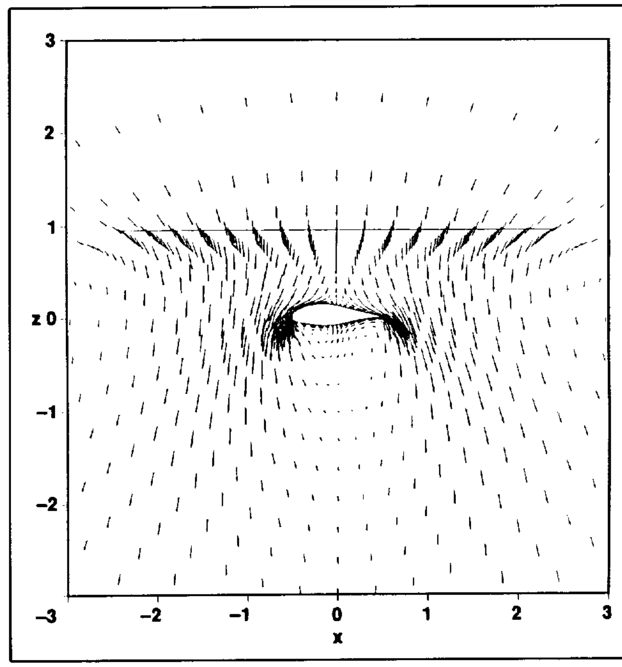
Tilt-Rotor Download Research

J. Light

Through a grant with Stanford University, computational fluid dynamics is being applied to the tilt-rotor wing download problem. A simplified configuration of a finite wing and rotor is being modeled, and computational results will be compared to measurements obtained in a parallel experimental program. The governing equations are the three-dimensional, thin-layer Navier-Stokes equations. The numerical solution algorithm is first-order accurate in time, implicit, and employs central finite differences for the spatial derivatives. The scheme is approximately factored and the resulting block matrices are diagonalized to increase computational efficiency. Grids have been generated both algebraically and by using an elliptic grid solver.

In a building-block approach, various subsets of the complicated, three-dimensional, tilt-rotor flow field have been modeled. Two- and three-dimensional free-stream computations on an airfoil and finite wing, respectively, have been made for low subsonic Mach number flows at an angle of incidence of −90°. Using a zonal approach, two- and three-dimensional computations of a rotor alone modeled as an actuator disk have shown the expected slipstream contraction and flow accelerations downstream of the rotor disk. Two-dimensional wing/rotor interaction has been successfully calculated.



Two-dimensional velocity distribution for a tilt-rotor/wing combination

A sample of the results is shown in the figure. The contraction of the rotor wake below the rotor and the separation of the wake over the wing are shown. Preliminary results in two dimensions for using leading-edge blowing to control the separation location look very promising.

Work continues on improving the three-dimensional results, creating smoother grids, applying a turbulence model, and developing a more accurate rotor representation.

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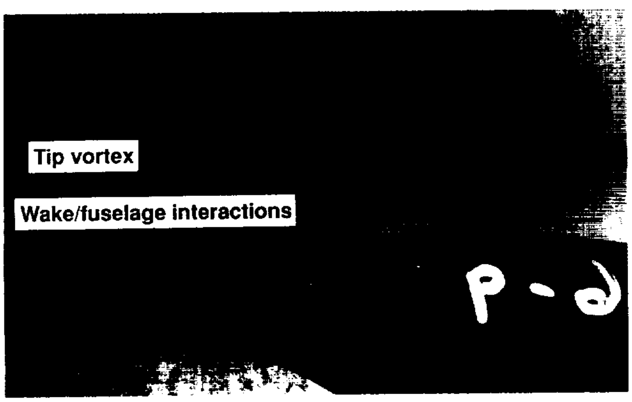
Shadowgraphs of Helicopter Wakes in Forward Flight

J. Light, A. Frerking, T. Norman

A test was conducted to examine the feasibility of using the wide-field shadowgraph technique for visualizing a helicopter rotor wake in forward flight. A wide range of test conditions was examined, which included thrust and forward speed variations.

Shadowgraphs were taken from the side and top of the rotor for advance ratios up to 0.175. One of the shadowgraphs is shown in the figure. This figure shows the downstream half of the rotor with the wind coming from the right. The tip vortex, a dark line below the rotor, can be seen convecting downstream. The interaction between the tip vortex and the fuselage can also be seen in the figure.



Wide-field shadowgraph of a helicopter rotor in forward flight

The wide-field shadowgraph technique can be applied to understanding various forward flight phenomena including wake geometry, wake/fuselage interactions, and blade/vortex interaction.

During the test a VHS video camera was also used for the first time to record the shadowgraphs of the tip vortices. The video camera eliminates the need for developing the photographs and provides instantaneous shadowgraphs. This allows the investigator to survey the flow field for specific areas of interest.

The video shadowgraph acquisition is promising because it can be coupled with new image processing software to allow data reduction from the videos. Software is being developed to obtain the tip vortex geometry coordinates from the videos.

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Aeroelastic Stability Program

R. Peterson, B. Lau

Current-generation helicopter rotor systems are sophisticated mechanical systems which operate with very high loads in an adverse aerodynamic environment. To relieve the high rotor-blade-root moments and maintain dynamic stability, helicopter rotor blades typically have several hinges, bearings, and/or dampers at the blade root. These mechanical devices operate in the rotating system and experience large oscillatory loads. They require frequent maintenance and can drastically reduce the reliability of the rotor systems. With the recent advances in high-strength composites, advanced rotor systems have been designed with a minimum of hinges and bearings. These systems have reduced the maintenance and improved the reliability without degrading the aerodynamic performance or aeroelastic stability.

Both full-scale and small-scale wind tunnel test programs, in addition to some flight tests, have verified the concept of such designs, as well as the structural and operational integrity of the rotor systems. However several very important areas of hingeless and bearingless rotor technology have not been adequately investigated. For example, the dynamic characteristics of these rotors in forward flight have not been adequately predicted using conventional analysis methods. One reason these rotors present a challenge is that their aeroelastic couplings change with flight conditions. Also, analytical modelling techniques are just beginning to predict the aeroelastic stability of these rotors at moderate and high forward flight speeds.

To address these and other problems, a BO-105 rotor system will be tested on the National Full-Scale Aerodynamics Complex Rotor Test Apparatus (RTA). This program will investigate the aeroelastic behavior of full-scale hingeless rotor systems. This program also involves correlation of rotor system performance and loads between 40% scale model of the BO-105 Helicopter, flight tests of a BO-105, and the full-scale wind tunnel results. To accurately measure both steady and dynamic rotor forces and moments, a rotor balance has been designed and fabricated for the RTA. This balance is being calibrated.

To expand the analytic capability of rotorcraft aeroelastic analyses, Syracuse University, the University of Maryland, and Georgia Tech are conducting studies under University Research Grants.

Syracuse University recently completed validating a Transfer Matrix approach for predicting aeroelastic stability of redundant load path bearingless rotor systems in hover. Forward flight formulations using the same Transfer Matrix approach were completed and are being implemented in a computer code.

Two efforts with the University of Maryland are under way. The first effort is the extension of the finite-element capability developed by the University of Maryland to handle coupled rotor/body problems with composite and elastic body degrees-of-freedom in forward flight. The second effort is the development of a comprehensive rotorcraft analysis code that integrates the various in-house codes developed at the University of Maryland into a singular code. The comprehensive code will be able to deal with a wide variety of rotor configurations while offering a user-friendly environment, ease of understanding, and modularity.

The existing codes at the University of Maryland are based on the state-of-the-art rotorcraft theories and numerical schemes. The codes provide a wide range of analysis options including nonlinear aeroelastic trim, steady-state response, stability analysis including ground and air resonance, higher harmonic control, aerodynamic modeling, gust response, large aircraft vortex encounters, aeroelastic optimization, circulation control, and analyses with composite blades.

Georgia Tech is developing an unsteady wake theory appropriate for aeroelastic analyses of rotors in hover and forward flight. The new theory will allow the use of improved aerodynamic modeling in analyzing practical rotor dynamic problems. This new theory is flexible in its application and has shown good correlation with experimental results. Current work involves application of this theory to rotorcraft elastic blades in hover and comparison with other theories and experimental data in forward flight.

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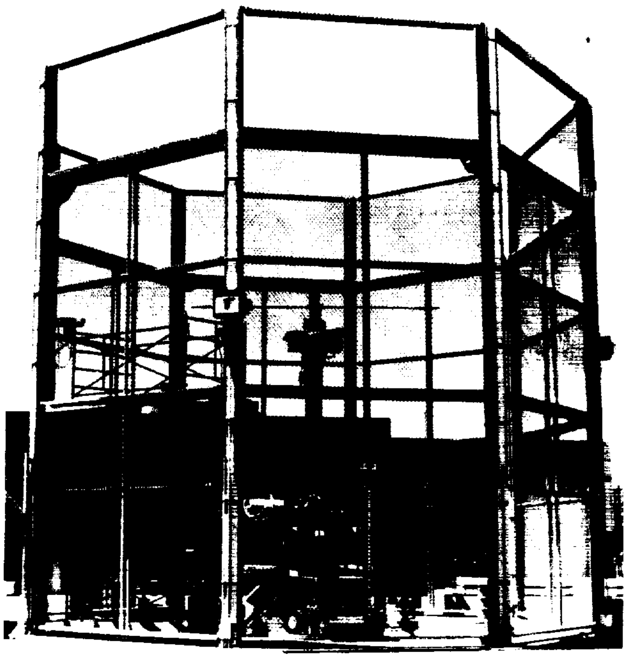
Light Helicopter, Experimental Risk Reduction and Demonstration/Validation Testing

R. Peterson, P. Shinoda

In support of the U.S. Army Light Helicopter, Experimental (LHX) program, the National Full-Scale Aerodynamics Complex (NFAC) provided test facilities and personnel to the two contractor teams for developing a next-generation helicopter design. The first test program with the McDonnell Douglas Helicopter Company and Bell Helicopter Company (Superteam) under the Risk Reduction effort was completed in the 40- by 80-Foot Wind Tunnel. A second test program with the Superteam under the Demonstration/Validation (Dem/Val) contract was scheduled for the second quarter of 1990. The third test program with the Boeing Helicopter Company and Sikorsky Aircraft Company (First Team) under the Dem/Val contract was scheduled for late in the second quarter of 1990.

The first test program with the Superteam was conducted in two phases. The first phase was conducted at the McDonnell Douglas Helicopter Company Remote Test Facility (RTF) with the objectives of acquiring data on isolated rotor hover performance and providing a complete checkout of their new test stand before it entered the 40- by 80-Foot Wind Tunnel. In the figure the test stand is shown



McDonnell Douglas/Bell LHX 1/2-Scale Rotor System at McDonnell Douglas Helicopter Company, Mesa, AZ, Rotor Test Facility

installed at the RTF. The second phase of the test program acquired both hover and low-speed rotor and airframe performance and anti-torque data, rotor dynamics and loads data, and rotor aeroelastic stability data.

The objective of the second entry into the 40- by 80-Foot Wind Tunnel will be the acquisition of data on hover and low-speed rotor and anti-torque performance, rotor dynamics and loads, rotor aeroelastic stability, rotor handling qualities, and high-speed rotor and airframe performance.

The test program with the Boeing Helicopter Company and Sikorsky Aircraft Company will be conducted in the 80- by 120-Foot Wind Tunnel. The objective of this test program is to obtain rotor hover performance and loads information. This test is to be conducted on the NFAC Rotor Test Apparatus (RTA) in simulated out-of-ground effect conditions. Steady and dynamic rotor forces and moments will be measured on the newly acquired RTA rotor balance.

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Long-Range Laser Velocimeter for the National Full-Scale Aerodynamics Complex

M. Reinath

Most instruments used for velocity measurements in wind tunnel flow fields rely on a sensor element mounted within the flow. This element occupies some physical space at the measuring location and creates a need for a support structure that must withstand the wind tunnel dynamic pressure.

In wind tunnels as large as those of the National Full-Scale Aerodynamics Complex (NFAC), this support hardware can become quite significant in size and cost, especially when measurements are required over a large region of the flow. Depending on the particular application, the element and the associated hardware can introduce potentially significant flow perturbations in the velocity field both at and around the measuring location.

An alternative method, which eliminates the sensor and greatly reduces the required support hardware, is the measurement of velocity by laser Doppler velocimetry.

To provide this capability for the NFAC, a long-range laser velocimeter (LV) was developed for remote operation from within the flow fields of these wind tunnels. The system is a confocal, two-color, dual-beam backscatter LV capable of measuring two orthogonal components of velocity simultaneously. Two interchangeable sets of zoom optics are used to make measurements to a maximum range of 20 meters. Position control of the measurement location within the flow is accomplished using stepper motors and absolute optical encoders which are connected to an onboard controller. A dedicated computer interfaced to the onboard controller remotely controls position and other functions while also buffering and reducing the LV data.

Two techniques are used for LV data acquisition. At measurement ranges of less than 10 meters, signals are relatively strong or photon-saturated, and counter processors are used to acquire the data. At ranges between 10 and 20 meters, signals are much weaker or photon-resolved, and a photon-correlation technique is applied to acquire and process the signals. This technique permits recovery of the

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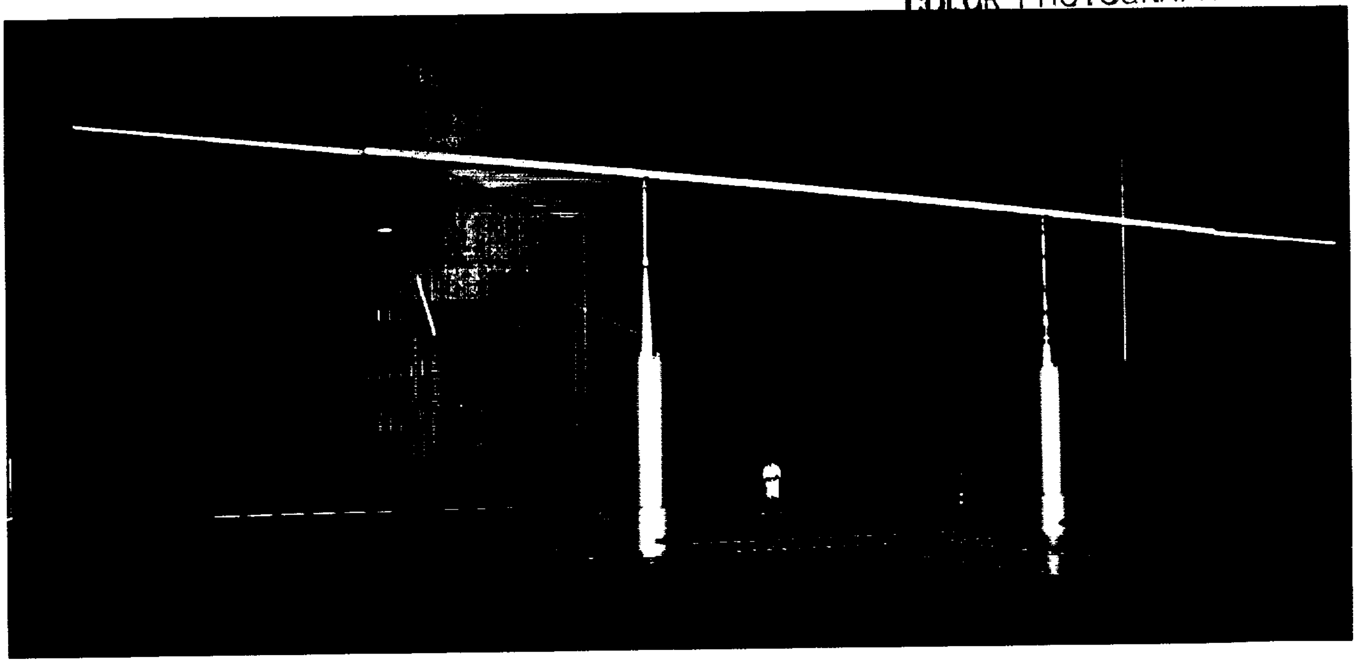
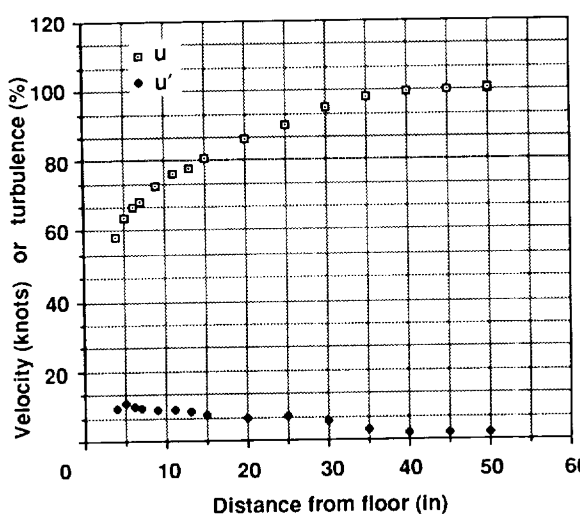


Long-range laser in the test section of the 80- by 120-Foot Wind Tunnel

velocity probability distributions at a particular measurement location from which the mean components of velocity and corresponding normal stress components of turbulence are obtained.

Velocity and turbulence intensity profiles were acquired during the flow calibration of the 80- by 120-Foot Wind Tunnel in the floor boundary layer along a vertical survey line located downstream of the model-support turntable. The relative position of the LV in the test section is shown in the first figure.

Attempts were made to acquire LV data relying solely on the natural seeding present in the flow. These were unsuccessful because of an insufficient data rate. Injection of artificial solid seed particles in the 3-micrometer size range at the wind tunnel inlet resulted in a substantial increase in data rate. Presented in the second figure are measurements of the horizontal component of mean velocity and turbulence intensity taken in the boundary layer.



Horizontal component of mean velocity and turbulence intensity in the floor boundary layer of the 80- by 120-Foot Wind Tunnel

The system has also been used for laser light-sheet flow visualization in the 80- by 120-Foot Wind Tunnel. The laser sheet is generated using a high-speed, galvanometer-driven mirror. The saw-tooth oscillation of the mirror produces a uniform wedge-shaped, 2-millimeter thick sheet as shown in the third figure. Scan rate and amplitude, as well as laser power, are adjustable. Smoke is injected into the flow and video images are recorded.

Long-range laser showing laser light sheet used for flow visualization

Testing of a vertical and short takeoff and landing (VSTOL) aircraft model hovering in the ground effect at the NFAC Outdoor Aerodynamic Research Facility was planned for spring 1990. LV surveys will be conducted to acquire velocity data in the ground environment around the model. Laser light-sheet flow visualization is also planned to study the problem of hot-gas reingestion.

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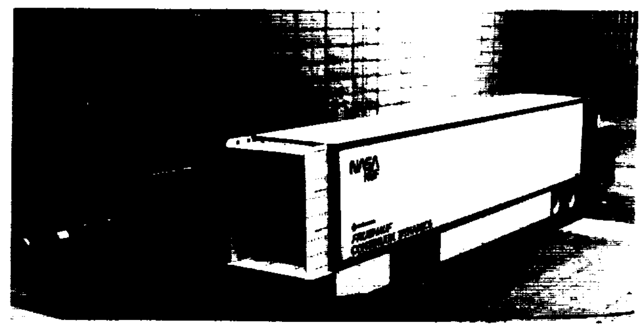
Base Drag Reduction Studies

J. Ross

Tests performed in the Ames Research Center's 80- by 120-Foot Wind Tunnel have demonstrated the aerodynamic drag reduction capability of a simple add-on device for tractor/trailer trucks. The device, referred to as an aerodynamic boattail, consists of four plates mounted perpendicular to the rear door of the trailer to form an open box slightly smaller than the perimeter of the trailer. The device mounted on the test vehicle in the wind tunnel is shown in the first figure.

The concept of aerodynamic boattailing was developed by Continuum Dynamics, Inc. (CDI) of Princeton, New Jersey, under a Small Business Innovative Research contract through the National Science Foundation. Phase II of the study contract culminated in the full-scale wind tunnel tests. Corporate sponsorship was also provided by Fruehauf Corp. and Navistar who made available the trailer and tractor, respectively, which were used during the test program.



Test vehicle (with boattail plates installed) in 80- by 120-Foot Wind Tunnel

Approximately 30 configurations were examined during the test program. The tests identified configurations which provided drag reductions of up to 10%, which corresponds to a 5% increase in fuel economy at highway speeds. On a typical commercial truck, this increase in efficiency can provide an annual fuel saving of 1000 gallons. If the entire fleet of tractor/trailer trucks in the United States were to use the device, approximately 1 billion gallons of fuel could be saved each year.

The function of the aerodynamic boattail is to trap a weak vortex at the rear of the trailer as shown in the second figure. Rotation of the vortex acts to turn the flow around the rear corner of the trailer, which in turn increases the base pressure over a majority of the rearward facing surface of the trailer so that the drag is reduced.

To better understand the increase in base pressure and the drag reduction provided by the boattail plates, both time-averaged and unsteady pressures on the aft part of the trailer were measured. These measurements added considerable insight into the

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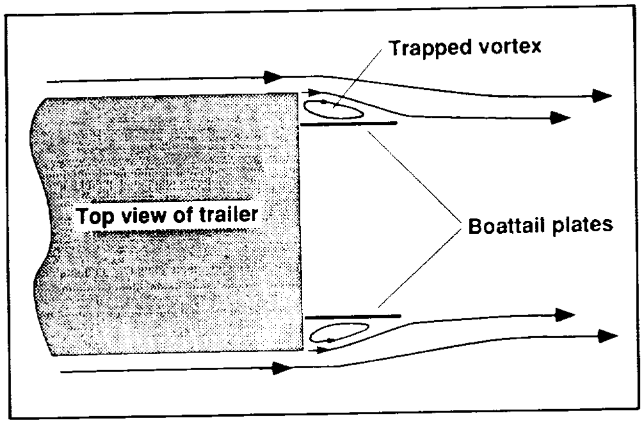

Operation of aerodynamic boattailing

fluid dynamic mechanisms responsible for the drag reduction. Extensive flow visualization of the wake region using smoke illuminated by a laser light sheet further clarified the flow field in the base region.

The tests were also used by NASA researchers to test computational fluid dynamics techniques (INS2D and INS3D). Data obtained during the wind tunnel test will allow evaluation of the accuracy of the computations for this class of bluff-body flows. Results of the analysis to date are in reasonable agreement with the experimental data and provide useful, detailed information concerning both base drag in general and the operation of the boattail plates.

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Tilt-Rotor Flutter Alleviation

J. van Aken

The University of Kansas Center for Research, Inc., under a cooperative agreement with Ames Research Center, is studying the potential of using active controls to delay or suppress tilt-rotor whirl-flutter type instabilities. The development of the next generation of tilt-rotor aircraft likely will be accompanied by an increase in maximum flight speed. Potential of the occurrence of whirl-flutter aeroelastic instability therefore is also increased and could form a limiting factor to the maximum speed capability.

A NASA-developed program, CAMRAD (for Comprehensive Analytical Model for Rotorcraft Aerodynamics and Dynamics), was used to obtain a set of linear differential equations, which describe the motion of the tilt-rotor aircraft at various speeds. CAMRAD output consists of the open-loop system matrices which describe the aircraft motion in the state variable domain. The matrices formed an input to a separate program, which performs the closed-loop, active-control calculations. This program performed an eigen analysis to determine the flutter stability for both the open- and closed-loop systems. Time response calculations were performed to estimate the magnitude of the required active control settings for closed-loop stability. The option existed to superimpose signal noise onto the closed-loop sensors.

A sensor model, based upon the feedback of pure state variables, was studied and it was shown that the onset of whirl-flutter for a baseline tilt-rotor aircraft could be delayed by feeding back the wing accelerations in the vertical and horizontal direction to the longitudinal cyclic.

A sensor model, which uses physically measurable signals, is being analyzed. An off-line structures program is used to calculate the free-vibration wing motion. The hub motion due to this wing/body vibration forms the standard input to CAMRAD, which provides the open-loop system matrices. The wing vibration characteristics are also used to define the closed-loop sensor model in the active-control program. The number of sensors and their location in the sensor model is varied to study the performance of various feedback control schemes on tilt-rotor whirl-flutter alleviation.

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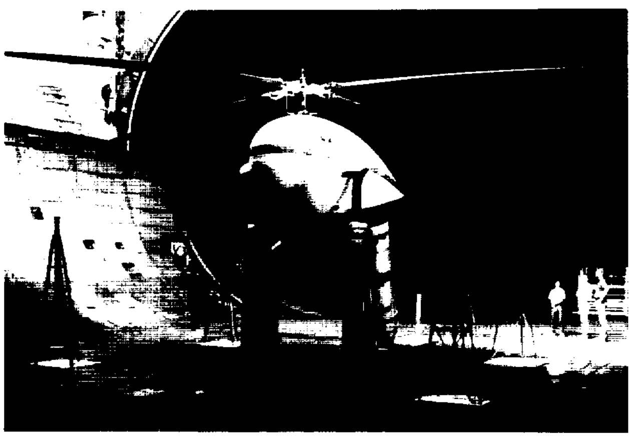
Aerodynamic Interaction Program

G. Yamauchi, T. Norman

A full-scale wind tunnel test to investigate rotor/fuselage aerodynamic interaction was completed. The model consisted of a Bell 412 main rotor and a modified NACA 0030 body of revolution. The fuselage loads were measured independently by load cells mounted on the test stand. Combined rotor/fuselage loads were measured by the tunnel balance system. In addition, fuselage steady and unsteady surface pressures, blade bending moments, control system loads, and mast bending moments were measured.



Bell 412 rotor on model 576 test stand

A wall correction method for rotors will be developed using the static pressure measurements acquired along the ceiling and side walls of the wind tunnel test section. Because this test will serve as a baseline for future tests involving main rotor/tail rotor acoustic interaction, isolated main rotor noise was also measured. This acoustics data set is the first for a full-scale rotor in the acoustically treated 40- by 80-Foot Wind Tunnel.

Three configurations were tested to isolate the effects of the rotor on the fuselage: fuselage alone, fuselage with hub (rotating), and fuselage with hub and rotor blades. Test variables were

1. Isolated fuselage–
   body angle of attack = 0° to –8°
   tunnel speed = 20 to 120 knots
2. Fuselage with hub–
   body angle of attack = 0° to –8°
   tunnel speed = 20 to 120 knots
   rpm = 324
3. Fuselage with hub/rotor–
   body angle of attack = 0° to –8°
   advance ratio = 0 to 0.30
   tip Mach number = 0.60, 0.68

Data reduction will be performed in addition to theory correlation. Additional phases of the interactional aerodynamic program include main rotor/tail rotor testing with the Lynx and Bell 412 tail rotors.

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Hub Drag Reduction

L. Young, D. Martin

For the last five years an experimental program has been under way at Ames Research Center to define low-drag hub and pylon fairings for helicopters. To date, four small-scale wind tunnel tests have been performed: the 1985 joint Ames/Sikorsky test (Army 7×10 #2); the 1986 Ames test (NASA 7×10 #1); the 1988 joint Ames/Langley test (Langley 14- by 22-Foot Wind Tunnel); and the 1989 joint Ames/Bell test (NASA 7×10 #1).

Test results from the first three wind tunnel tests identified a promising category of fairing configurations for low-drag helicopters: cambered hub fairings are used in conjunction with airfoil-contoured pylon fairings such that both fairings are integrated together with only a minimal gap separating them.

The fourth test builds upon this past work and has the following objectives: (1) to evaluate the impact of hub rotation and blade shanks on the Ames low-drag fairings identified in the three previous tests, (2) to compare the fairing drag to that of a more rigorous hub and rotor mast model than was done in the earlier tests, and (3) to provide an opportunity for an industry participant to directly compare their low-drag hubs and fairings against the Ames fairings.

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The Bell 222 powered model with the unfaired 680 hub

The Bell 222 powered model with hub and pylon fairings

The technical approach for the joint Ames/Bell hub drag reduction test has been to refine Ames and Bell low-drag fairing concepts to address pragmatic flight-vehicle implementation concerns, and to implement these fairings on a 1/5-scale Bell 222 powered model with a simulated 680 rotor hub and blade shanks. Angle-of-attack, yaw angle, and hub revolutions per minute sweeps are performed for each fairing configuration. Three different pylon fairings, two hub fairing thickness ratios, and three different hub- and pylon-fairing integration approaches are being studied during the joint Ames/Bell hub drag reduction test.

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Networks for Image Acquisition, Processing, and Display

A. Ahumada, Jr., A. Watson

The human visual system consists of networks that sample, process, and code images. Understanding these networks is a valuable means of understanding human vision and of designing autonomous vision systems based on network processing. Ames Research Center's Human Interface Research Branch has an ongoing program to develop computational models of such networks.

The models predict human performance in detecting targets and in discriminating displayed information. In addition, the models are artificial vision systems sharing properties with biological vision that has been tuned by evolution for high performance in complex, dynamic environments. Properties include variable-density sampling, noise suppression, multiresolution coding, and fault tolerance. The research stresses noise analysis in visual networks, including sampling, photon, and processing unit noises.

Program accomplishments include the development of the following models and procedures:
1. models of sampling array growth with variable density and irregularity comparable to that of the retinal cone mosaic,
2. noise models of networks with signal-dependent and signal-independent noise,
3. models of network connection development for preserving spatial registration and interpolation,
4. multiresolution encoding models based on hexagonal arrays (hexagonal oriented orthogonal quadrature pyramid transform),
5. mathematical procedures for simplifying analysis of larger networks.

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Map Frame of Reference and Spatial Cognition

V. Battiste

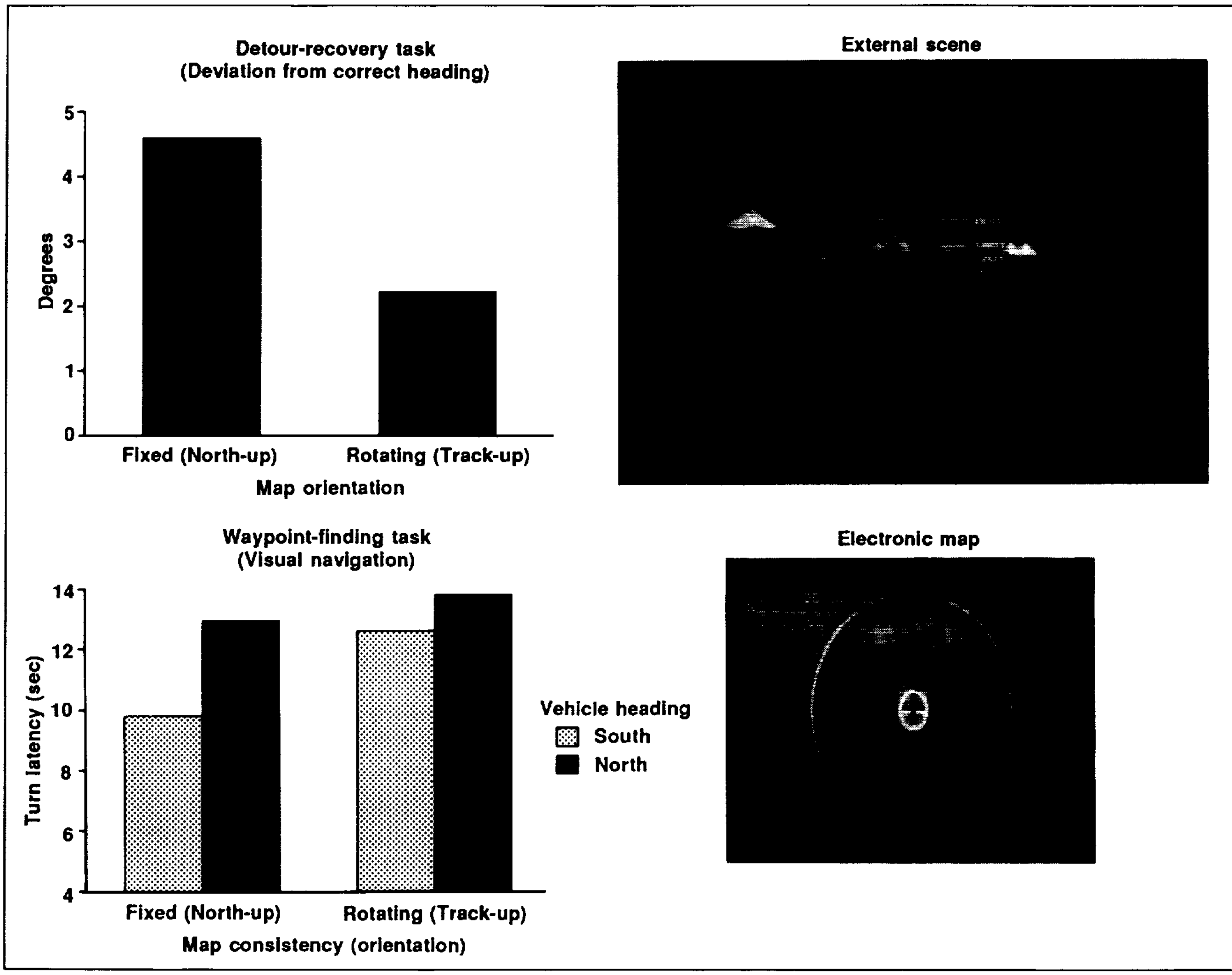
When flying at low altitudes, helicopter pilots must rely on direct visual cues (for immediate orientation to the environment) and on information presented on cockpit displays (to remain geographically oriented). Research has begun at Ames Research Center, the University of Illinois, and Stanford University to develop improved electronic map display formats. One goal is to reduce the cognitive and perceptual load imposed by the requirement to relate information in the visual scene to electronic map displays in the performance of various navigation tasks.

Previous research comparing north-up (fixed map) to track-up (rotating map) orientations revealed no consistent advantages for one format over the other. The research suggested that these differences are task-dependent; that is, active navigation seems to benefit more from a rotating map, while planning activities benefit more from a fixed map. The two factors that mediate these advantages seem to be the cognitive reversals and mental rotation required when navigating southward (using a fixed map) and problems associated with cognitive planning activities when object locations are inconsistent (using a rotating map).

NASA has funded research at the University of Illinois to investigate the relative costs and benefits of fixed (north-up) and rotating (track-up) electronic maps for helicopter navigation tasks. Twenty pilots flew simulated low-level and nap-of-the-Earth missions using either north-up or track-up maps. The pilots responded to displayed navigational commands that directed them to fly to certain landmarks in the simulated world (wayfinding). Periodically, they had to integrate information presented on the map and in the forward field of view (FOV) to estimate the distance between two landmarks (only one of which was visible in the forward FOV), regain their original flightpath (after a detour), and identify the location of a lightning strike visible in the forward FOV using map coordinates. In addition, the degree to which color coding could lessen deficiencies in particular map/task combinations was examined.

In general, the effects of color coding were weak. Performance on the wayfinding, distance estimation, and localization tasks generally favored the fixed map; while reorienting to the flightpath after a detour, clearly favored the rotating map. However, performance with the fixed map was sensitive to heading; the fixed-map advantage was lessened for tasks performed while flying south.

The results were modeled in terms of two important cognitive components of navigational tasks: (1) locating objects (or own position) on a map in absolute coordinates, and (2) orienting the vehicle relative to a landmark in the environment and deciding which way to turn.



Map frame of reference and spatial cognition

Locating objects depends upon consistent geographical representations and is disrupted by the inconsistent physical locations of objects on a rotating map. Orienting to landmarks in the environment (an ego-referenced judgment) is impaired when the world view and map views are not consistent (e.g., when the aircraft is headed south, but the map is oriented toward the north). Different tasks show differing degrees of dependence on these two cognitive components.

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Human Factors Issues in Civil Medevac Operations

V. Battiste, J. Shively

Although Emergency Medical Service (EMS) helicopters play a critical lifesaving role, they have the worst safety record of any segment of aviation. Since 1980, the EMS industry has averaged 12.3 accidents per 100,000 flight hours. In a recent survey, the National Transportation Safety Board cited weather-related factors as the most significant influence. However, program competition, demands by medical personnel, crew schedules, and pilots' "can do" attitudes, create an environment that precipitates errors and poor pilot judgment.

The high EMS accident rate demands an immediate solution; however, imposing new regulations without the benefit of adequate research will not solve the problem. Thus, NASA researchers have begun several activities in this area.

Two government/industry workshops were held for representatives from the private, public service, and military organizations responsible for medical evacuation where they discussed common experiences, problems, and solutions. The EMS Safety Network was established within the framework of the Aviation Safety Reporting System (ASRS) to develop a comprehensive data base of civil, public service, and military medevac incidents which can be analyzed to assess the influence of different factors on pilot performance and flight safety. This data, in conjunction with in-flight assessments of public service and hospital-based medevac crews, will focus subsequent research efforts on the most critical issues. An in-flight evaluation of helicopter law enforcement crews was performed to assess the use of research methods proposed for use in EMS helicopters.

An in-flight evaluation of EMS flight crews was completed in 1989. The field study investigated (1) pilot workload, (2) pilot decision making, (3) cues used to maintain geographical orientation, and (4) communications. The pilots identified four factors as the most significant contributors to workload: communication problems, time of day, weather, and traffic density.

Emergency Medical Service helicopter

Missions flown to accident scenes were given the highest workload ratings, while hospital transfers were given the lowest. Unlike the typical pattern, workload did not vary significantly between takeoff, cruise, and landing segments. However, workload was higher for outbound legs than for either transport or inbound legs, even if a patient was on board.

To improve pilots' abilities to evaluate relevant factors and to make more appropriate decisions, a pre-flight risk assessment procedure (SAFE) was developed and tested in this study. The system was designed for use by pilots, hospital personnel, or administrators to predict the risk of an EMS mission, based on factors shown to affect mission success: weather, crew, mission type, organizational, and aircraft factors. Data from this study will be used to refine the system and to improve the accuracy of its predictions.

To identify the features EMS pilots use to maintain geographical orientation, pilots completed a questionnaire and drew a map of the route flown after each mission. The maps showed that EMS pilots use specific cultural and natural features (lakes, mountains peaks, cities, and bridges) more often than linear features (rivers, valleys, and powerlines). Two pilots overestimated distances close to their base hospital, while the reverse was true for the others.

Responses to the questionnaire were compared to those from four non-EMS pilots with similar flight experience. While EMS pilots rely on memory for flight planning, the other pilots use maps. EMS pilots use pilotage and radio navigation, while the other pilots use pilotage, dead reckoning, and radio navigation.

Both groups estimated spending the same amount of time on flying (58%), navigation (25%), maintaining geographical orientation (15%), and communications (3%).

The differences between EMS and other pilots may be due to (1) the limited time available for EMS mission planning, (2) single-pilot EMS operations, and (3) EMS pilots' greater knowledge of their service area. Additional analyses of the map drawings and in-flight communications are in progress.

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Synthesis and Psychoacoustic Evaluation of Early Reflections in Modeled Environments

D. Begault

Headphone sound can be filtered according to head-related transfer functions (HRTFs) to achieve convincing simulations of azimuthal positions. However, front-back reversals and externalization (distance) problems remain when these data are used in binaural sound simulators such as the Ames Research Center convolvotron.

Front-back confusion and externalization problems may arise when a listener cannot completely infer a spatial dimension to a received sound. Headphone sound can be transformed from intracranial positions (lateralization) to extracranial positions by transforming the signal according to the "typical" acoustical properties of environmental contexts.

A synthesis-based method for this type of transformation has been developed that uses spectral modification algorithms based on physical modeling of these environmental contexts. A synthesis-based approach is useful because it can be added in a post-production process and it allows parametric psychoacoustic evaluation.

Ames researchers have developed software that allows specification of a given number of early reflections based on a ray-tracing technique. Other variables include the frequency response of boundaries, orientation and configuration of source and listener, and shape and size of the environmental context. These reflections are directionalized using the pinnae transform technique so that the reverberation is listener-based.

Control of the spatial dimension of sound offers great potential in developing advanced human-machine interfaces, particularly in developing aural icons for contexts where multiple channels of information must be monitored simultaneously. Successful implementation of HRTF-based, three-dimensional auditory displays depends on the elimination of front-back reversals and improvement of imagery externalization.

The inclusion of synthesized early reflections can also be applied to an *echolocation cueing system* within a virtual environment context (such as the Ames Virtual Interactive Environment Workstation (VIEWS) project). Echolocation allows the operator of such a system to simultaneously attend to the semantic qualities of speech or auditory icons while providing a naturalistic system for cueing proximity to boundaries. By including binaurally based, early reflections into a spatial auditory display, echolocation can be used by the operator of a VIEWS system to avoid collisions.

This research is being jointly funded by NASA and the U.S. Navy Office of Naval Research.

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Traffic Alert and Collision-Avoidance System

S. Chappell

The Traffic Alert and Collision-Avoidance System (TCAS) is a stand-alone system that can detect the presence of any transponder-equipped aircraft that is within a prescribed envelope around a TCAS-equipped aircraft. TCAS can provide the pilot with a visual display showing the relative position, distance, and altitude of other aircraft. TCAS II also evaluates the closure rates and flight geometry of other aircraft relative to itself. If TCAS II calculates that a collision threat exists, it will issue visual and verbal vertical maneuver commands to the pilot. TCAS can "see" other aircraft even though the pilot may not be able to; for example, during conditions of reduced visibility or high workload.

The aviation industry looks to Ames Research Center for guidance in evaluating many human factors issues, such as:

1. pilot interpretation of the information that TCAS makes available,
2. pilot acceptance of the display format chosen by the manufacturers,
3. pilot willingness to trust a system that commands the pilot to make sometimes abrupt, evasive maneuvers because of unseen traffic,
4. pilot response time and success rate,
5. system configuration changes introduced by industry,
6. the integration of TCAS into the routine operating environment already in the cockpit.

Ames researchers have conducted TCAS experiments using currently working airline crews flying typical airline flights to both metropolitan destinations and outlying airports. These experiments explored:

1. TCAS II with part- and full-time traffic display, and with no traffic display, just maneuver information;
2. pilot performance with and without target areas displayed on the vertical speed indicator;
3. pilot execution of the commanded maneuvers in different aircraft performance regimes.

As the nation's airlines begin to operate TCAS-equipped aircraft on routine daily flights within the national airspace system, the human interface will be evaluated more fully. Future research will explore presentation of lateral maneuvers for TCAS III.

This research is being jointly funded by NASA and the Federal Aviation Administration.

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Crew Factors in Aircrew Performance

T. Chidester, B. Kanki

Ames Research Center's Crew Research and Space Human Factors Branch, with additional funding from the Federal Aviation Administration, recently completed the Crew Composition Simulation to determine whether individuals with differing personality profiles influence the crew performance process in aerospace operations. Twenty-three fully qualified B-727 crews completed a 1 1/2 day full-mission simulation of aviation operations.

Crews were contrasted by the personality profile of their captain. Three profiles were identified: (1) Positive Instrumental/Expressive (IE+), (2) Negative Instrumental (I–), and (3) Negative Expressive (Ec–). The effect of the captain's personality profile was assessed along with expert ratings, crew errors, and aircraft handling parameters.

Statistical analyses revealed the following trends:

1. crews led by captains fitting the IE+ profile showed consistently effective performance,
2. I– captains led crews who were ineffective on the first day but highly effective on the second, suggesting a familiarity effect,
3. Ec– captains led consistently less effective crews.

This study was initiated to determine whether personality is an important variable affecting group performance. Results presented here clearly suggest that the personality of a crew leader is significant. Given these results, selection approaches should be seriously and carefully considered.

The more traditional approaches to the study of communication have typically failed to consider the fundamental interactive and sequential organization of the communication process among individuals. Understanding these processes is crucial in predicting overall crew performance because the processes are mechanisms by which crew members coordinate activities, relay information, and solve problems. In addition, the design of "artificially intelligent" machines that will interact efficiently with humans depends on accurately determining how humans efficiently communicate with each other.

The program has produced new techniques for analyzing sequential and interactive speech patterns that are now being applied in both natural and high-fidelity simulated environments which are analogously related to space operations. Communication patterns that differentiate high-error crews from low-error crews have been identified, including distinctive differences in their use of question-answer and command-acknowledgment sequences, as well as differences in the relative rates of overall communication and nonresponse. At higher levels of analysis, it has also been found that the degree of homogeneity in speech patterns is greater for low-error crews while high-error crews show greater heterogeneity and less predictable forms of speech response.

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Evaluating Voice-Activated Controls

C. Coler, M. Bortolussi

Low-level rotorcraft operations continue to impose high visual and manual demands on pilots. Voice recognition systems have been proposed as an alternative method for pilots to enter commands and effect subsystem selections. Vocal commands should compete less for pilots' limited manual-control resources than manually entered commands during flight segments that impose high manual-control demands.

Ames Research Center and the U.S. Air Force jointly conducted a series of simulations to determine the performance and workload benefits that might be derived by using vocal controls.

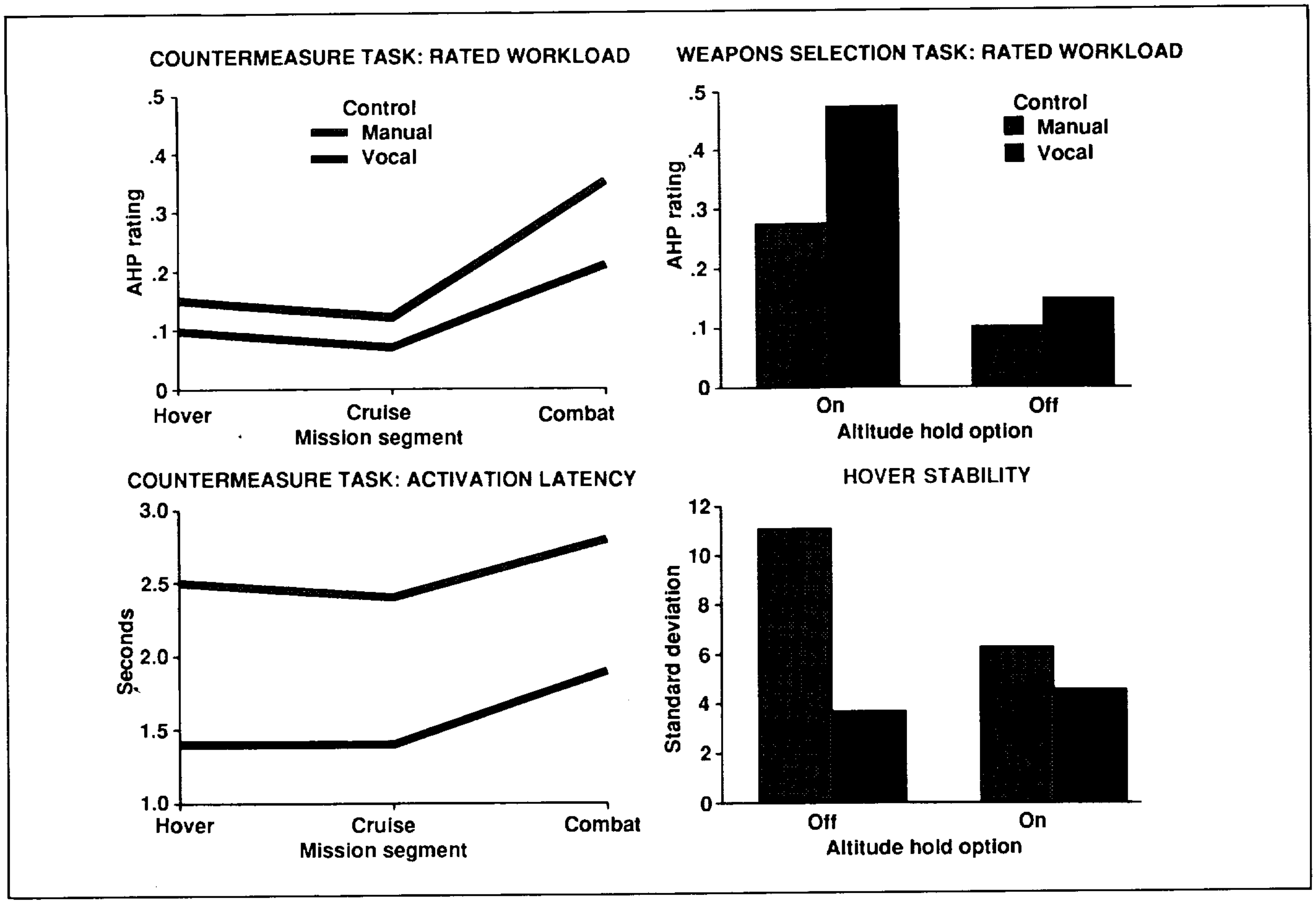
Research was conducted using a fixed-base simulation of an advanced-technology military helicopter. Pilots conducted missions that included cruise, hover, and air-to-ground engagement segments. Control over various discrete tasks (weapon selection, data-burst transmission, countermeasure activation) was effected by voice command or manual button press.

In the second simulation, a pilot-selectable altitude-hold feature was provided on half of the flights. In addition, simulated wind gust disturbances were introduced at different times during performance of the discrete tasks to determine the temporal pattern of disruptions with the two methods of entering commands.

In the first study, speech controls improved performance by reducing competition for manual response resources. Discrete-task performance was degraded less during high-workload segments and vehicle stability was improved. However, this performance benefit was achieved at the expense of higher workload. Uttering consistent voice commands to achieve adequate recognition accuracy and monitoring feedback to ensure that the intended command was entered required additional time and effort.

A second simulation replicated the earlier study and evaluated the effect of automation (a pilot-selectable altitude-hold option) on performance with vocal or manual controls. When altitude-hold was not available, results of the first experiment were replicated. Vocal commands took longer to enter than manual, but they interfered less with the performance of the flight-control task than did commands entered manually during high-workload segments. Workload was higher with speech controls than with manual.

With the addition of altitude-hold, however, the differences between vocal and manual input systems disappeared. Altitude-hold reduced overall workload to the point that pilots had sufficient reserve capacity to control the vehicle and enter discrete commands



Results of voice-activated controls evaluation

(with either input device) without becoming overloaded. Although altitude-hold did not affect data-burst performance, weapons-selection response times improved. On the other hand, vehicle-control performance was worse when unexpected events occurred, suggesting a reduced level of involvement or decreased readiness to respond.

Data from these simulations support the predictions of the multiple-resources theory and suggest the potential utility of speech controls in reducing competition for manual response resources, even though current voice-recognition system technology is not yet adequate to encourage their operational use for high-priority tasks.

This research forms the basis for a principled assignment of vocal controls to the performance of discrete functions in advanced rotorcraft. This will ensure that maximum improvement in workload and performance will be achieved by introducing voice recognition systems when adequately reliable and capable systems are available.

Since human factors guidelines for the application of voice-recognition technology in advanced rotorcraft do not yet exist, work is under way at Ames to develop such guidelines. Airborne tests will be performed to develop and evaluate vocabularies and syntax for a variety of applications, such as data requests and control of avionics.

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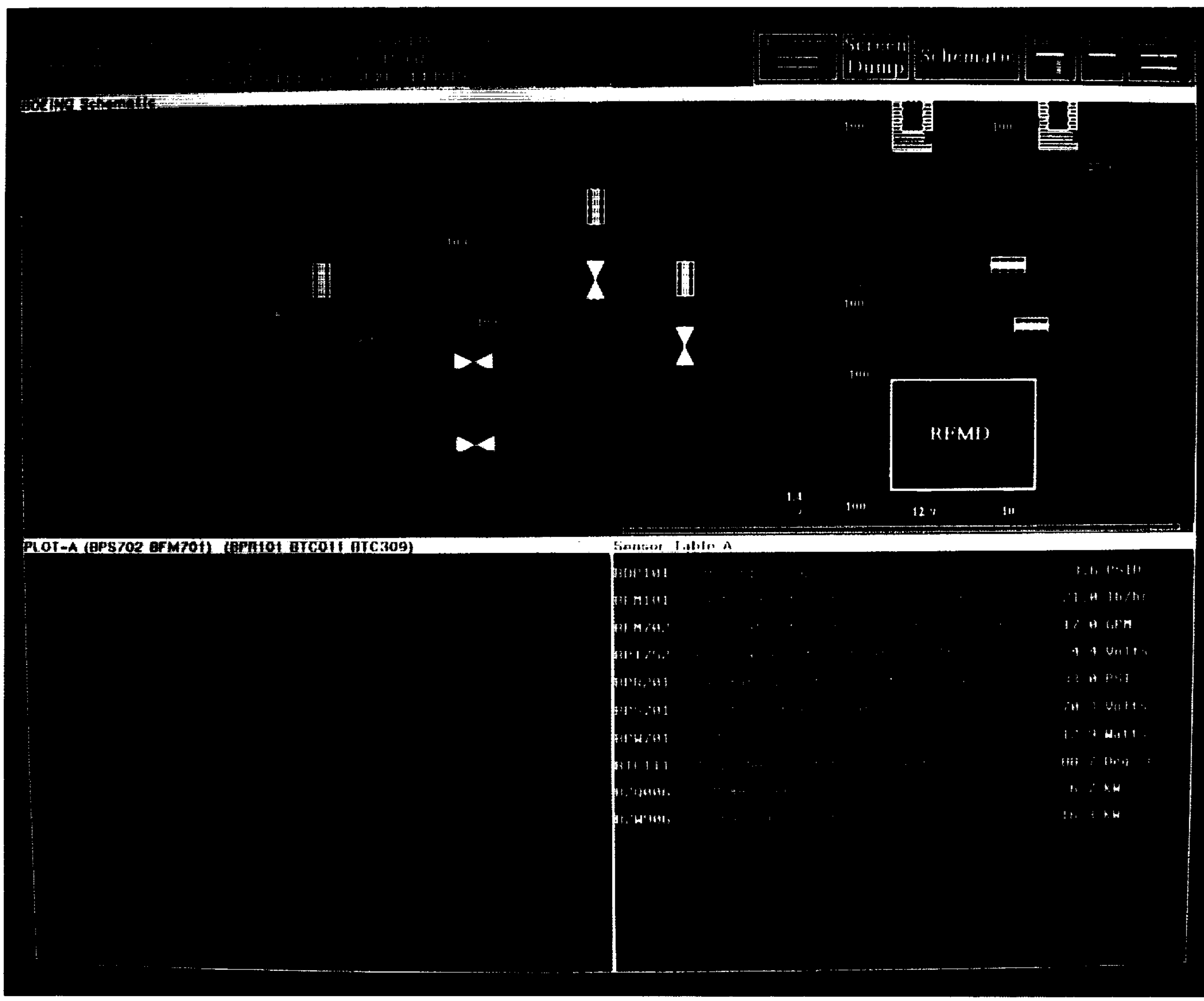
Human Interface to the Thermal Expert System

N. Dorighi

The Human Interface to the Thermal Expert System (HITEX) is part of the Systems Autonomy Demonstration Project (SADP). In this project, a thermal expert system (TEXSYS) monitors, advises, and diagnoses faults on a thermal testbed developed by the Boeing Aerospace Corporation and located at Johnson Space Center (JSC). The Ames Research Center Aerospace Human Factors Research Division is responsible for HITEX in a cooperative effort with the Information Sciences Division.

The goal of HITEX is to provide a useful tool to aid thermal engineers in validating system performance. HITEX provides an interface to both the thermal testbed and the expert system controlling it. As such, it is implemented with two side-by-side screens: one color graphics monitor for real-time data displays and one black and white monitor for communicating with TEXSYS. One Symbolics computer with a single keyboard and one "mouse" pointing device are used for the two screens.



Sample HITEX screen showing thermal schematic, time-history plots, and sensor table

ORIGINAL PAGE IS OF POOR QUALITY

ORIGINAL PAGE COLOR PHOTOGRAPH

A Schematic Toolkit was developed at Ames to allow graphical schematics with underlying data structures to be quickly and easily built. This generic tool can be used to build schematics for other physical systems as well.

HITEX was delivered to JSC in April 1989, and through June it was further enhanced, based on direct feedback from end users. It has been integrated into the TEXSYS computer and the data acquisition system developed at JSC. The formal week-long demonstration will take place in August 1990.

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Integrated Rendezvous and Proximity Operations Displays

S. Ellis, A. Brody

The purpose of this research program is to provide and evaluate display concepts for space station proximity operations displays or other generic displays of relative orbital position. The display concepts will emphasize the use of metrical computer graphics to present spatial information to astronauts or other occupants of a space station.

As part of this program, an interactive proximity operations planning system has been developed which allows on-site design of fuel-efficient, multiburn maneuvers in a multispacecraft environment such as that surrounding a space station. Maneuvering takes place in, as well as out of, the orbital plane.

The difficulty in informal planning of such missions arises from higher-order control dynamics resulting from the unusual and counter-intuitive character of relative orbital motion trajectories and complex operational constraints. This difficulty may be overcome by visualizing the relative trajectories and the relevant constraints in an easily interpretable graphic format to provide the operators with immediate feedback on their design actions.

The new display uses inverse dynamics to remove control nonlinearities associated with orbital maneuvering and provides a graphic tool for visualizing structural, plume-impingement, and velocity constraints on orbital maneuvering. Two experiments evaluating performance of untrained users have been completed and have shown that very brief training periods are needed to learn to plan orbital maneuvers with this system.

The visualization providing this feedback shows a perspective "bird's-eye" view of a space station and co-orbiting spacecraft referenced to the station's orbital plane. The operator has control over two modes of operation: (1) a viewing system mode, which enables exploration of the spatial situation surrounding the space station, and (2) a trajectory design mode, which allows the interactive "editing" of way-points and maneuvering burns to obtain a trajectory complying with all operational constraints. Thus, through a graphically aided interactive process, the operator may continue improving the design until all constraints are met.

An experimental program in which operators design a series of missions varying in complexity and constraints has begun. Operator actions (that is, viewing system or trajectory design) were recorded. Review of the trajectory design characteristics is used to identify the heuristic design rules which may be used in an automated design system.

Experimentation with the improved display has uncovered a new visual illusion associated with three-dimensional interpretation of multiorbital trajectories. Careful selection of the display's viewing direction may control this problem, but continued research into required geometric, symbolic, and computational enhancements is needed to further optimize presentation of the three-dimensional orbital information.

This continuing work is conducted jointly by Ames Research Center, Israel Institute of Technology (Technion), and University of California, Berkeley.

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Virtual Interactive Environment Workstation

S. Fisher, M. McGreevy, E. Wenzel, J. Larimer

The application of human capabilities outside vehicles and shelters will be a vital element of space station, Moon base, and Mars exploration missions. Because extravehicular activity (EVA) will account for much of the human presence and robots will assist with many chores, telepresence and interactive visualization systems will be needed to provide essential crew performance enhancement capabilities.

To support NASA's mission requirements for augmented human capability, the Human Interface Research Branch continues developing the Virtual Interactive Environment Workstation (VIEWS). This device is a multisensory personal simulator and telepresence device. It consists of a custom-built, wide field-of-view, stereo, head-mounted display; a custom video processor; magnetic head tracker; fiber optic gloves; magnetic gesture trackers; voice input/output; and an audio symbology generator.

VIEWS is being developed to improve situation awareness in complex spatial environments; to enable high-fidelity telepresence for controlling telerobots; to simulate workstations, cockpits, and module interiors; and to improve scientific visualization interfaces for exploring planetary surface data.

In 1989, the third-generation monochrome viewer and video processor electronics were completed. Ad hoc demonstration software was replaced by a system software library for programming the viewer, the tracker, and the glove. A directional acoustic signal processor, the "convolvotron," was designed and is being fabricated. Initial operational configuration (IOC) of the prototype system should be achieved by the end of 1990. Upon reaching IOC, the hardware and software will be integrated into a stable configuration for user interface research, and generic development will end. Recently, a major documentation activity was completed, and technology transfer activities are increasing.

Application software is being developed for a joint effort between Ames Research Center and the Jet Propulsion Laboratory (JPL) in which VIEWS will be used to provide an alternate operator interface in telerobotics supervisory control.

In another project, a highly dextrous anthropomorphic end-effector being developed at JPL and the Ames VIEWS will demonstrate high-fidelity dextrous telepresence between Ames and JPL.

As part of the Pathfinder Humans-in-Space Program, user interfaces for virtual exploration of planetary surfaces will be developed. Users will be able to explore the planets as integrated environments, not merely through individual pictures.

As a spinoff to aeronautics research, specific plans are being developed to provide systems for use in rotorcraft helmet-mounted display research and computer-aided cockpit design.

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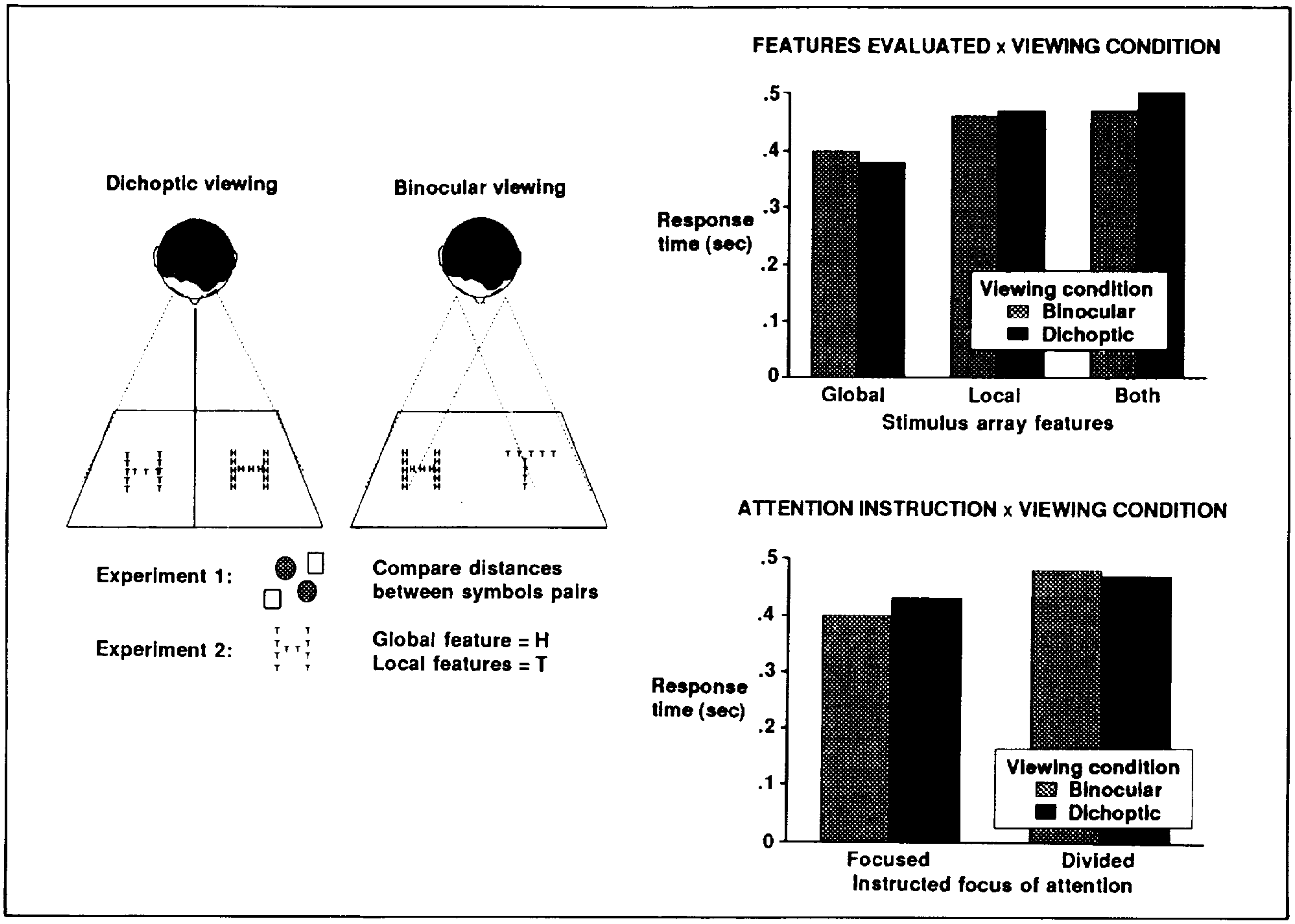
Cognitive Factors in Visual Attention

D. Foyle

NASA funding was provided to begin a research program at the Technion, Israel Institute of Technology, for examining the cognitive and perceptual demands placed on helicopter pilots using helmet-mounted displays (HMD) of sensor imagery for low-level missions at night and in reduced visibility. The goals are to establish guidelines for using monocular, biocular (both eyes view identical image), and binocular HMD formats; and to propose more effective methods of improving pilots' abilities to use the devices.

In the first experiment, dichoptic presentation (different information presented to each eye) and normal binocular presentation were contrasted by



Experimental conditions and results for the study of visual attention under dichoptic and binocular viewing conditions

requiring subjects to judge which of two pairs of geometrical shapes were closer together. Binocular trials presented both pairs side by side, while dichoptic trials presented different pairs to each eye. On different trials, subjects were instructed to focus or divide their attention between the two fields.

Results suggested that people can, in fact, focus their attention on information presented to one eye or the other (attention can compensate for the interference from the other visual field), but that it is difficult for them to divide their attention between two (different) visual fields. It demonstrated humans' abilities to use the two eyes as separate information channels and the importance of attention strategies for efficient information processing.

Experiment 2 investigated the perception of global and local features of compound visual patterns presented binocularly or dichoptically. Again, subjects were instructed to either *focus* (search for targets at either a local or global level) or *divide* their attention (search for a target at either level) on different trials. Again, focused attention resulted in faster reaction times and fewer errors than did divided attention, and no performance difference was found between dichoptic and binocular viewing conditions.

The third experiment measured performance as a function of target size and level (global or local) in compound stimuli under focused or divided attention, with dichoptic or binocular viewing conditions. Again, no performance differences were found between dichoptic and binocular presentation, and performance was poorer with divided attention than with focused attention. A performance advantage was found for larger targets in the divided-attention condition, but not in the focused-attention condition.

These data suggest that people can process information presented independently to the right and left visual fields without a significant performance decrement (in comparison to normal binocular viewing), despite the fact that dichoptic presentation is not a natural situation. They can process this information at either global or local levels of detail. The most important factor seems to be whether the task requires focused attention (one feature of a compound stimulus or one visual field) or divided attention (global as well as local features, right and left visual fields). The consistently poorer performance found when attention was divided demonstrates the important role of central processes in visual perception.

Research is under way to examine the effects of interfering movement in the irrelevant visual field and of foveal versus peripheral presentation of information in the relevant or irrelevant eye. Experiments using a helmet-mounted sight will be performed in a motion-base simulator. Subjects will fly using the helmet display while monitoring a panel-mounted cathode-ray tube (time-sharing between a dynamic continuous task and a static, discrete task).

A second condition will present different dynamic visual displays to the two eyes: a narrow field-of-view display on the helmet and a projected "out-the-window" display. Fields of view, displaced viewpoints, and image brightness will be manipulated to simulate in-flight conditions with helmet-mounted displays.

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Influence of Visual Cues on Performance with Simulated Sensor Imagery

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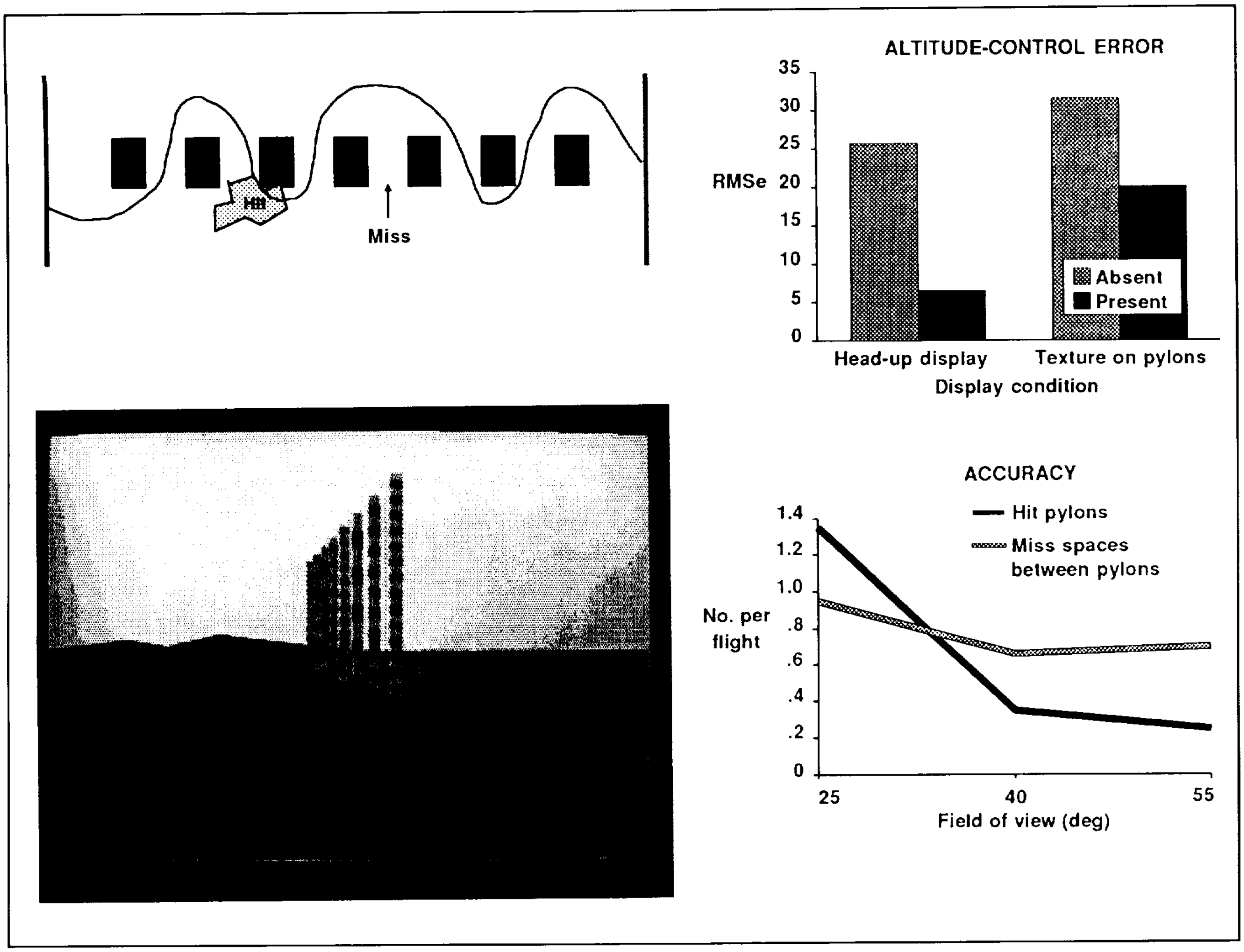
Displays of thermal imagery provided by infrared sensors allow pilots to conduct missions at very low altitudes at night and in low visibility. With current systems, pilots experience increased workload during such missions and they are unable to achieve the same performance that is possible with direct vision.

Thermal imagery differs from direct vision in quality (lower bandwidth) and content (visual displays represent thermal differences rather than brightness contrasts). Research is under way at Ames Research Center to quantify the characteristics of thermal imagery that most significantly influence human performance. Three-part task simulations were conducted to investigate the influence of surface texture on the ground and objects in the scene, field of view (FOV), and superimposed symbology on pilots' abilities to maintain a designated altitude in forward flight and to fly a slalom course.

In the first experiment, subjects flew through a slalom course (created by evenly spaced pylons in a simulated "thermal world") while maintaining a constant altitude. On different flights, surface texture on the terrain and/or on the pylons was either present or absent. Head-up display (HUD) symbology was superimposed on the visual scene on half of the flights. Both HUD and surface texture significantly reduced altitude control error. However, hits (of the pylons) and misses (of the intervals between them) were significantly greater with the HUD. Hits and misses were not affected by the presence or absence of texture on the ground or pylons.

In the second experiment, subjects were instructed to maintain a constant altitude and course while flying across terrain (with and without surface texture) in which pylons were present on some trails (with or without surface texture) and not on others. Again, the presence of surface texture on the ground or on objects in the environment improved altitude control; altitude error was within 4-5% of the target altitude value with any type of texture and 11-15% with no texture. However, texture on both the ground and objects in the environment did not further improve performance.

In the third experiment, subjects flew a slalom course at a constant altitude, at speeds of either 81 or 108 knots. Three FOV were presented: 25°, 40°, and 55°. Although ground texture was present in half of the flights, it had no influence on performance. The number of pylon hits and the number of intervals between pylons missed decreased signifi-



Experimental tasks and results in the assessment of the effects of sensor imagery parameters on flight control

cantly as FOV was increased from 25° to 55°. Pylon hits were more frequent at the higher speed. Time to complete the course was significantly greater with the wider FOV.

These results demonstrated the importance of high-frequency visual cues to flight control. They suggest that other means of displaying essential information should be provided to improve pilots' performance with thermal displays, where some visual cues may be missing. The interference between HUD symbology and pilots' abilities to use information in the visual scene suggests that an alternative means of providing necessary information about vehicle status might be considered. Finally, interesting differences in control strategies were found; subjects appeared to focus more on avoiding the pylons than flying through the intervals between the pylons in the correct sequence.

The differential effects of FOV on pylon hits/interval misses and flying time suggest that subjects did not adapt their flying strategy to changes in FOV. They appeared to perceive each display as representing the whole world (rather than a variable viewport into a larger world) as they failed to appropriately use surface texture to correctly scale the world. Hence, they tended to keep the pylons as far away as possible, but visible on the screen. This resulted in distances that were too close with a 25° FOV (resulting in more hits) and too far with a 55° FOV (resulting in longer flying times).

Additional research is under way to examine the influence of FOV and the interaction of spatial frequency (in the visual scene) and superimposed symbology with a more realistic visual display and an irregular slalom course (to prevent the development of rhythmical flight-control strategies).

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Individual Crew Factors in Flight Operations

R. Graeber, L. Connell

The focus of this program is to assess the effect of fatigue and circadian rhythmicity on flight crew performance and to determine the contribution of factors associated with operational parameters, individual differences, and crew behavior. The approach is to combine limited laboratory and simulator research with an extensive set of field studies documenting the physiological and behavioral responses of flight crews operating in a variety of flight environments.

This is the first major attempt to objectively study these issues in both commercial and military flight crews. Increasing pressure for smaller and more productive crews requires a better understanding of how and why pilot performance can be degraded. The introduction of highly automated, two-person crew, long-range aircraft has further increased the pressure for understanding the impact of these factors.

It will be possible to improve flight safety and efficiency by (1) developing guidelines for rulemaking and aircraft certification, (2) designing individual pilot coping strategies, and (3) making operational recommendations to air carriers.

Research has concentrated on field studies using cockpit observers and continuous physiological monitoring in several types of flight operations (international long-haul, overnight cargo, and helicopter). Additionally, a cooperative program with research organizations and airlines in West Germany, the United Kingdom, and Japan has enabled the collection of electroencephalography (EEG) sleep data during layovers on eastward and westward polar routes through Anchorage, Alaska, for comparison with home recordings made before and after the trips.

Data collection has been completed on long-haul crews, North Sea helicopter crews, overnight cargo crews, and international polar crews. Technology transfer to the industry is occurring through interaction with the Federal Aviation Administration (FAA) aircraft certification teams and two U.S. Pacific carriers, and development with a U.S. manufacturer of a crew alertness support device for long-haul glass cockpits. The FAA, unions, and management of two airlines have approved a full-mission, long-haul simulation study and an in-flight EEG study of preplanned cockpit rest has begun.

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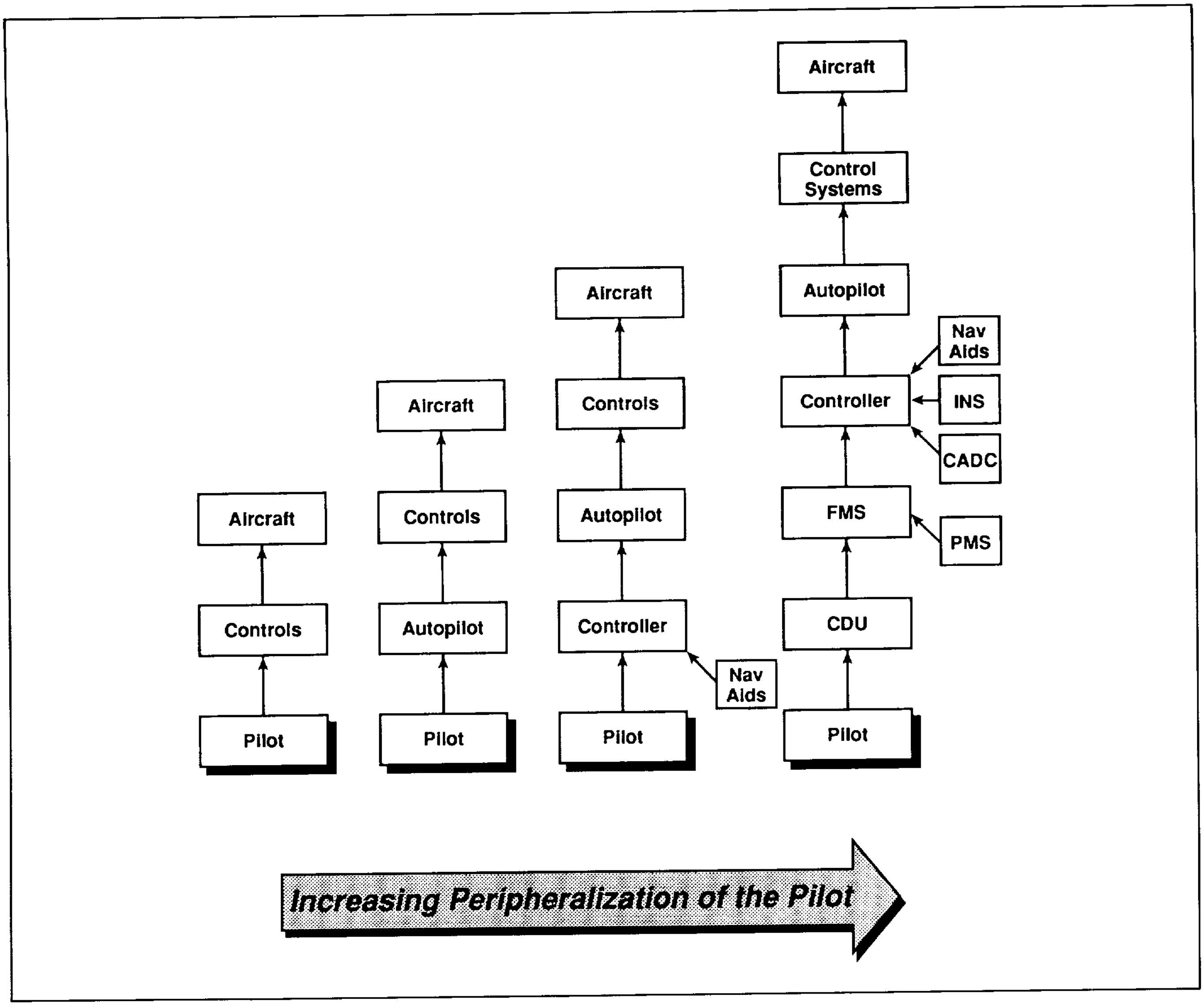
Evolution of Transport Aircraft Automation

R. Graeber, C. Billings, E. Palmer, III, S. Norman

Although much has been accomplished regarding flight deck automation, there is still much to do. Technological advances have not only made possible new forms of errors, but they have also made the flight crew more peripheral to the actual operation of the aircraft (see the figure).

A NASA/Federal Aviation Administration (FAA)/ Industry workshop devoted to flight deck automation was organized by the Aerospace Human Factors Research Division of Ames Research Center. The August 1988 workshop provided an opportunity for representatives from airframe manufacturers, air carriers, the National Transportation Safety Board (NTSB), the FAA, NASA, and universities to exchange experiences regarding operations and training for automated aircraft. Additional exchange opportunities provided by the relevant organizations and government agencies would be beneficial.

The need for quantifiable data regarding implementation and interface designs for automated systems is also apparent. Full mission simulations,



Technological advances have resulted in an increasing peripheralization of the pilot

which compare alternate displays, etc., and test the performance of the entire system (air traffic control + flight crew + aircraft) would be helpful. Improvement in the human factors aspects of the certification process is needed.

Additional research is needed to better understand how to support the human role in an automated environment. This involves interface design, training, and operational procedures.

Improving our understanding of the air-ground interface is crucial for the future. This development is necessary if coordination of the planning and implementation of advanced automation for both the flight deck and the air traffic controller are to proceed in an integrated manner. Automation provides the potential for one part of an automated system to affect another, sometimes without direct human intervention. As a result, it is important to examine the implementation of automation as an overall *system* so that the design implications can be made visible before the operational phase begins.

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Strategic Behavior/Workload Management Program

S. Hart

Many measures and predictors of pilot workload have been developed that provide useful information in the design, evaluation, and operation of complex systems and that aid in developing models of human attention and performance. However, the relationships between such measures, imposed task demands, and measures of performance remain complex and even contradictory.

It appears that an important factor has been ignored. People do not passively translate task demands into performance. Rather, they actively manage their time, resources, and effort to achieve an acceptable level of performance while they maintain a comfortable level of workload.

While such adaptive, creative, and strategic behaviors are the primary reason that human operators remain an essential component in all advanced human-machine systems, they also result in significant variations in the ways that different operators respond to the same task demands. This, in turn, creates increased variability in measures of workload and performance and inconsistent relationships among different measures. In addition, individual differences in skill, motivation, and operator state further contribute to the variability.

Finally, we are able to measure workload and performance, but interpreting such measures remains difficult. For example, it is still not clear how much workload is "too much," "too little," or "just right." And, the consequences of suboptimal workload levels on system performance and the mental, physical, and emotional well-being of the human operators are unknown.

For this reason, Langley Research Center, Ames Research Center, and the U.S. Air Force Armstrong Aerospace Medical Research Laboratory established a joint research program. Goals of the 5-year program are to (1) determine how changes in strategies affect operator workload and system performance, (2) develop figures of merit that reflect the overall quality of performance, (3) identify optimal (and suboptimal) workload regions, (4) quantify the performance, subjective, and physiological symptoms of suboptimal levels of workload, (5) develop measures to estimate an operator's functional state, (6) develop improved predictive methodologies, and (7) establish techniques to improve an operator's abilities to manage workload extremes.

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Use of Computer "Games" in Flight Training

S. Hart

The use of special-purpose computer "games" for training has been proposed as one method of reducing training time and cost. Computer games are inexpensive and intrinsically motivating, and they can require some of the same skills used in flying. Underlying assumptions are that (1) skills developed in one environment generalize to the performance of similar tasks in other environments, and (2) physical fidelity may not be as important in the development of some skills as the fidelity with which skill components are represented. However, the degree to which flight skills might be improved by exposure to a carefully constructed "game" that is structurally, rather than physically, similar to the task of flying has not been determined.

Researchers from the Technion Institute in the Israeli Air Force Flight School, funded by a NASA grant, performed an operational test of the concept. A complex computer game was used that requires the development of attention management skills and the ability to cope with high workload. The basic game design and training philosophy were funded by the Defense Advanced Research Projects Agency Learning Strategies Project. However, the game was modified to improve its relevance to the skills developed in initial flight training (precise manual control, spatial orientation, representation and retrieval of procedural knowledge, division of attention, planning, and efficient visual scanning techniques).

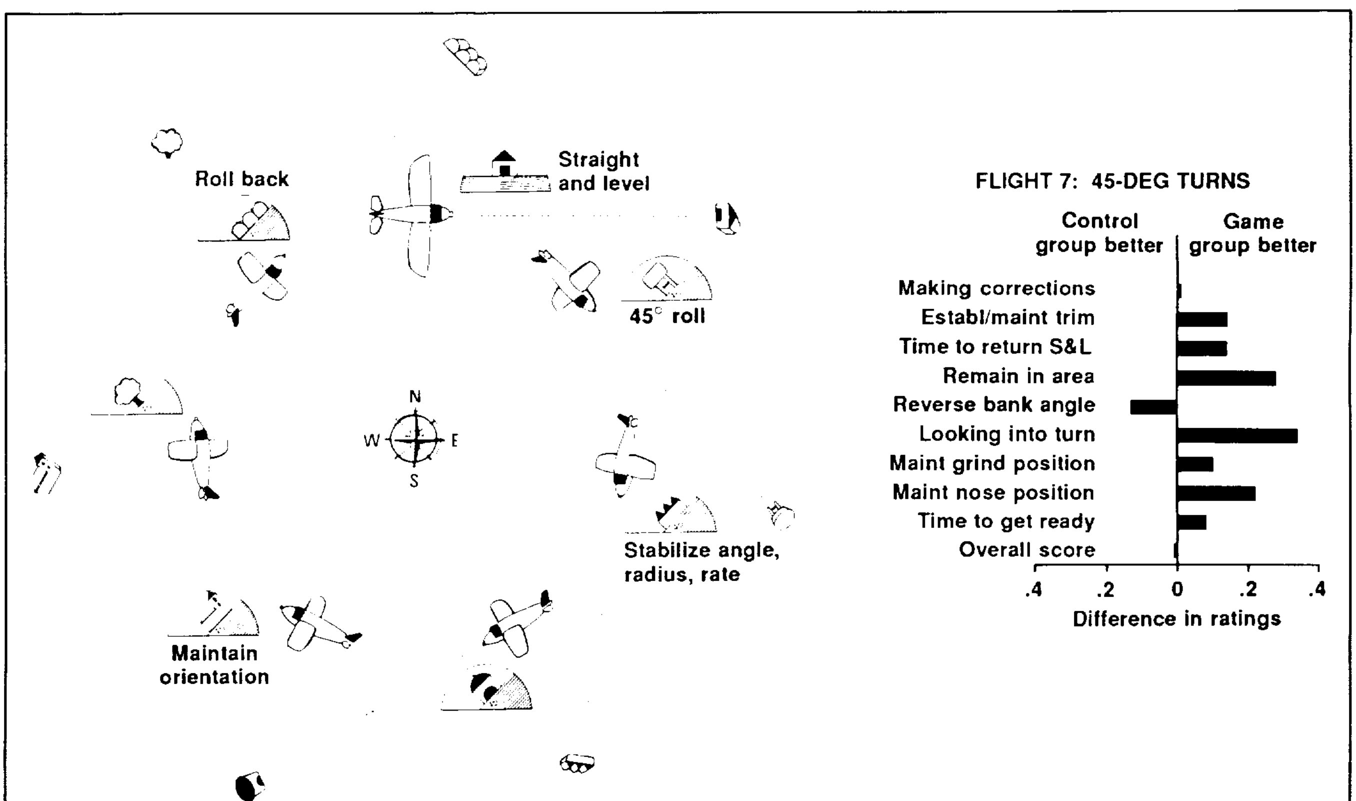
A different training method was given to each of three groups of Israeli Air Force pilot-trainees, matched on the basis of selection test scores. The experimental groups received 10 hours of training on the game with (Full Training) or without (Partial Training) specialized instruction to aid the pilots in generalizing their game experience to flight school. The control group received no game experience. In all other respects, the pilots' flight-school experiences were identical. Flying skills of all trainees were assessed by Israeli Air Force flight instructors during the first eight flights in the second phase of flight training.

Although the Full Training Group out-performed the Partial Training Group on the game itself, their performance in flight school was similar. However, there was a highly significant difference in flight performance between the pilots who had game experience and those who did not. The performance advantage for the pilots with game experience increased as the workload and the complexity of the training flights increased.

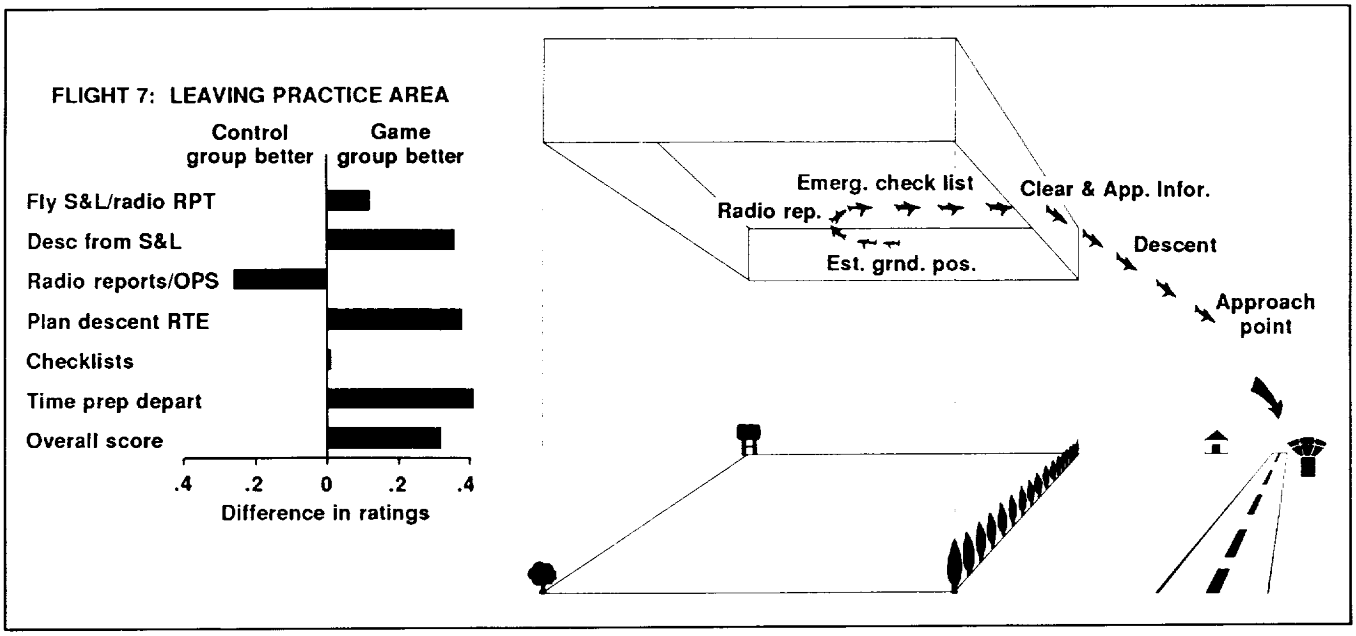
For example, the game groups out-performed the control group on all but 2 of the 17 flight skills that were evaluated in Flight 7 (see the figures). Interestingly, one of the two activities for which the control group out-performed the experimental group was radio communications, a skill that was not addressed by the computer game.

At the end of the eighth test flight, it appeared that the time-sharing and workload-management skills developed with the game had increased the probability that trainees would complete flight school by as much as 30%. However, by the time that the pilots completed flight training 1 year later, the differences had increased even more—50% more of the pilots with game experience completed flight school than did those without game experience.

Although low-cost computer games have been proposed as training tools for years, this is the first operational test of the concept. During FY 1990, a replication of this study will be performed in the Aviation Training Center at Ft. Rucker with the cooperation of the U.S. Army.



Flight 7: 45° turns



Flight 7: leaving the practice area

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Computational Human Engineering Research

E. Hartzell

The U.S. Army-NASA Aircrew/Aircraft Integration (A^3I) project is a joint Army and NASA research effort to produce a Human Factors-Computer Aided Engineering (HF-CAE) system called MIDAS (Man-machine Integration Design and Analysis System). The project's goal is to produce a human factors engineering tool to assist design engineers in the conceptual phase of rotorcraft cockpit development and to anticipate crew training requirements. The system provides designers with interactive, analytic, and graphical tools which permit early integration and visualization of human engineering principles.

Seventy to 80% of the life-cycle cost of an aircraft is determined in the concept design phase. After hardware is built, mistakes are difficult to correct and concepts are difficult to modify. Engineers responsible for developing crew training simulators and instructional systems begin work after the cockpit is built; that is, too late to impact its design. The HF-CAE tools give designers an opportunity to "see it before they build it," to ask "what if" questions about all aspects of crew performance including training, and to correct problems early. The current MIDAS system is focused on helicopters, but it is generic and permits generalization to other vehicles.

The MIDAS HF-CAE system is similar in concept to computational tools such as finite element stress analysis and computational fluid dynamics which are used to improve designs and reduce costs. Results of the computational analysis are presented *visually*. The MIDAS uses models of human performance and a computational simulation of "manned flight" to evaluate the cockpit design. Results are presented graphically and visually to the design engineers, often as a computer animation of manned flight.

Major elements of the MIDAS system are (1) automated mission editor; (2) designer's simulation workbench including aircraft dynamics and guidance models, human behavior/performance models, system function models, and workload models (from the Rotorcraft Human Factors Research Branch); (3) training requirements models; (4) three-dimensional computer-aided design utilities for cockpit layout, instruments, and controls; (5) anthropometric pilot model (graphic manikin); (6) designer's data, information, and analysis center; and (7) simulation and integration executive control system.

The project began in fall 1984 and has completed three major development phases toward a 1994 target date for a full prototype system. The current phase focused on expanding several elements of the system. The National Research Council's 2-year pilot performance model study is complete and has been published.

Two applied models of visibility and legibility are planned for inclusion in the system in the next phase.

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Visually Guided Control of Motion Workshop

W. Johnson

A cross section of talented researchers from academia, industry, and government participated in a 3-week workshop held at Ames Research Center to examine, develop, and test theories of self-motion perception and manual control. The goal was to enhance interest in, and thereby accelerate, the development of explicit models relating pilots' use of dynamic visual information sampled through windows or pictorial displays to manual control strategies in current- and advanced-technology aircraft.

Control-theoretic models, which typically assume that pilots use instruments (or cognitive equivalents) and aircraft states to guide vehicle control, were reviewed. In general, they were found to be inappropriate for low-altitude flight, where pilots rely on cues in the visual scene rather than on flight instruments. Methods were explored to expand these models to encompass the dynamic optical cues that provide information about the three-dimensional structure of the surrounding environment that pilots actually use in visually guided flight.

Coordinating the efforts of experts in the fields of self-motion perception and manual flight control was a complementary concern. These two groups have interacted little in the past, possibly because of the complexity of individual problems. For example, psychological research conducted to identify the visual information responsible for perceiving spatial orientation and self movement has relied upon the responses of passive observers, rather than the performance of active controllers. Methods for expanding this type of research to include active, "man-in-the-loop" methodologies were explored.

A closely related focus was examining the relationships among perceptual information, spatial (dis)orientation, and the control of self motion. Recent models of disorientation, and the related symptoms of motion-, space-, and simulator-sickness have described the etiology of these phenomena in terms of disrupted relationships between normal perceiving and acting. This work is particularly critical in designing displays for advanced cockpits and visual systems for flight simulators, where the movement of virtual eyepoints, vehicle control activity, and vestibular information are often decoupled or distorted.

This workshop resulted in a summary of the comparisons made among competing theories and methodologies performed in part-task simulators and computer simulations and the "cross-fertilization" among researchers representing competing, as well as congruent, theoretical approaches.

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Crew Factors in Environments Analogous to Space Operations

B. Kanki, T. Chidester

In conjunction with the National Oceanic and Atmospheric Association (NOAA) and the National Undersea Research Center of Fairleigh Dickinson University in St. Croix, U.S. Virgin Islands, Ames Research Center's Crew Research and Space Human Factors Branch investigators have incorporated the Aquarius undersea habitat as a space station analog environment. The unique undersea setting makes available a natural field situation for systematically observing teamwork and various issues of habitability under relatively isolated and confined conditions.

During FY 1988, data collection was completed for six teams of oceanographic researchers living and working on the ocean floor for 7 to 14 days in the Aquarius saturated habitat. Additional teams completed dives in FY 1989.

Before the dive, each team member completes a battery of measures which includes the personality scales used in the crew composition simulation and other social/organizational questionnaires. Crew members completed daily and post-dive surveys, which, taken with systematic ratings made by topside personnel and the on-site Ames investigator, combine to form an integrated performance measure of task productivity, crew satisfaction, and operational safety.

A methodology for making video-taped observations of habitat activities has been developed for focusing on (1) within-habitat team interaction, and (2) the interface between habitat and topside teams. Research instruments for investigating habitability issues pertaining to food and sleep have been developed for implementation in FY 1990.

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Visibility Modeling Tool

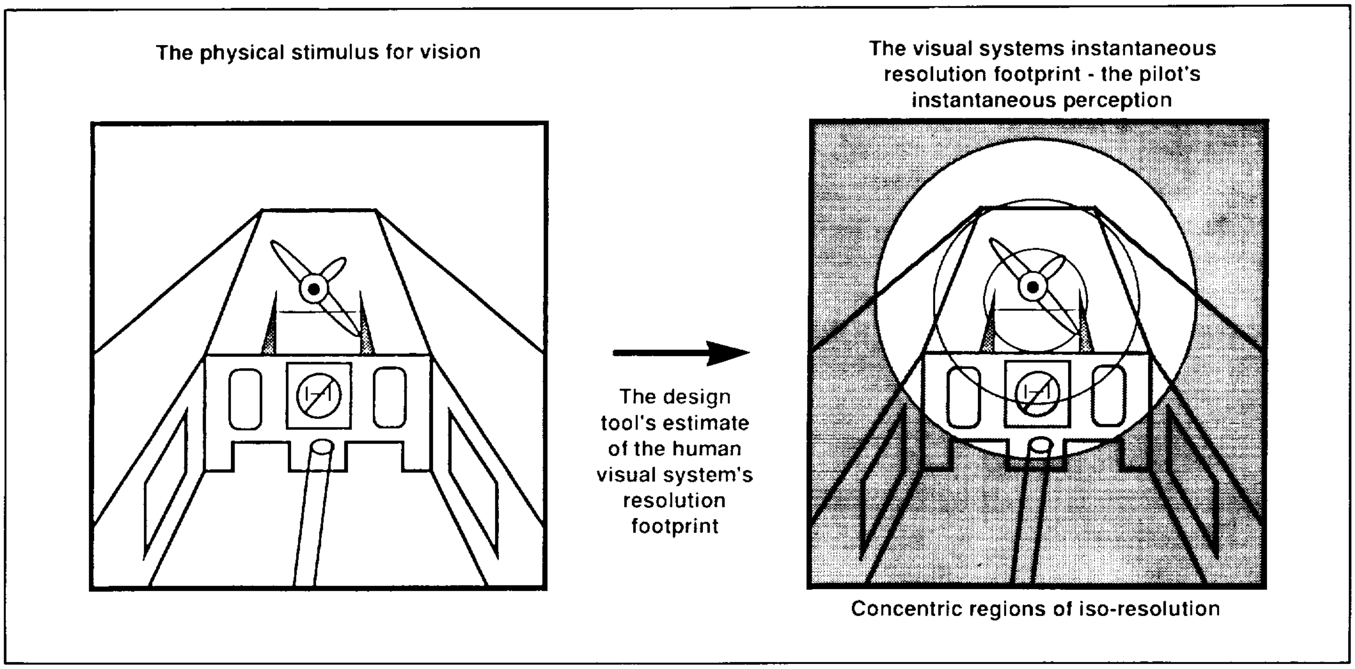
J. Larimer

Computer-aided engineering (CAE) has revolutionized the way engineers create designs. It is now possible to use mathematical models of objects or processes to evaluate the performance of a design before the object is built. Classic examples include the finite element analysis of strength used to evaluate the forces acting on structures, such as bridges, and the computational analysis of fluid dynamics or computational fluid dynamics models used to evaluate the lift properties of wings.

The Visibility Modeling Tool is a human factors (HF) CAE tool designed to help the crewstation design engineer answer questions about the visibility of information in potential avionic displays. The primary goal of this HF-CAE visibility tool is to evaluate potential designs before they are built, thereby reducing design costs, enhancing the quality of the design engineer's product, and shortening the design time line. For this tool to be maximally useful the evaluation that it provides to the engineer must be in an easily understood format. Thus, user friendliness through graphics is another goal of the project. The Visibility Modeling Tool is being developed as an integrated component of the U.S. Army-NASA Aircrew/Aircraft Integration (A^3I) HF-CAE system.

To model visibility it is necessary to consider (1) the three-dimensional (3-D) geometry of the crewstation or cockpit; (2) the reflective and emissive properties of surfaces and objects in that space; (3) ambient lighting; (4) the pilot's or astronaut's eye points; (5) what he or she is looking at; (6) how this affects convergence and accommodation; (7) far, near, and retinal obstructions such as window posts, helmet margins, and retinal insensitivities; and (8) the current adaptation state of the pilot's visual system. These factors are being incorporated into the visibility modeling tool at a level of realism that will generate reasonable, valid estimates of visibility.

The program is a mixture of in-house effort and grants and contracts with leading scientists at universities and research institutions in the fields of



Visibility modeling applied to cockpit design and evaluation: Computational models of human visibility

vision research and computer graphics. This mixture of effort is vertically integrated and spans problems of basic vision science to the application of 3-D models to problems in computer-aided design (CAD).

Two grants and a contract are in place. In addition, there are collaborative agreements and a university consortium agreement on closely related topics in human vision. Much of the system's basic computer system architecture has been developed and tested (i.e., communication protocols and system integration); there is a 3-D CAD system for rapid prototyping of cockpits and cockpit avionics; and a 3-D pilot manikin is being integrated into the system.

In the next phase, a computational model for the pilot's volume visual field will be added and a model of the legibility of letters and symbols will be integrated into the system. Basic developmental work continues on modeling accommodation; i.e., human optical blur, surface quality, and ambient lighting.

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U.S. Army funded

Information Management and Transfer

A. Lee

The effective management and transfer of information within the National Airspace System (NAS) is critical to a safe and efficient air transportation system. Future NAS operations will require flight-deck information management systems designed for optimal transfer of airborne, ground, and satellite information to aircrews. Information management principles are required which define the information needed, and when and in what form it should be provided.

Ames Research Center has an ongoing research program to develop and verify design principles for, and demonstrate the viability of, advanced information management systems for future air transport operations. The program's goal is to develop design principles for advanced flight-deck information management systems and to develop computer-aided design technology to facilitate the integration of new information technology. Since air-to-ground, as well as airborne, information transfer is a part of this research, aircraft/air traffic control (ATC) integration in the future NAS will benefit from this effort.

A multifaceted approach has been undertaken to attain the program goal by FY 1992. This approach includes the development of methodology for quantifying aircrew information requirements and information processing capacity during all flight phases, identification of current operational problems that could be eliminated by improved system design, development and evaluation of prototypical information management systems, development of part system simulation technology as a low-cost design and evaluation tool, and development of computer-aided design technology based upon information management principles.

During FY 1989 a number of efforts were successfully completed in support of the program objectives. Analyses of the NASA Aviation Safety Reporting System incidents of information transfer factors contributing to in-flight weather encounters were completed, in addition to a comprehensive survey of air carrier aircrew weather information requirements. A line-oriented flight simulation study was conducted to evaluate the effectiveness of ground-air transmission of microburst/windshear information. The study revealed that significant improvements in aircrew planning and decision-making could be realized with the use of data-link-transmitted weather information.

In support of advanced communications management system development, prototype data entry and retrieval systems to support digital air-ground communications were developed. The first phase of a Massachusetts Institute of Technology (MIT) grant to develop and evaluate flight-deck interfaces for automating ATC clearance delivery was also completed. Study results indicate significant enhancements in flight management systems operation with graphical interfaces using clearance information transmitted by data link.

With regard to future air-ground communications management efforts, it is planned to develop improved flight-deck data-link communications interfaces for time-based clearance delivery and related digital communications interfaces. A cooperative agreement between Ames Research Center and Stanford University has been initiated to examine pilot/controller communication errors in actual ATC operations. Results of this study should provide a better understanding of the potential effect of data-link communications and provide a basis for subsequent flight-deck display design.

The second phase of MIT grant research will concentrate on determining the interface requirements for four-dimensional navigation in a data-link-supported ATC environment. To improve aircrew planning and decision-making behavior in weather avoidance, continued research in weather information management will include the development and evaluation of a weather information systems architecture with emphasis on terminal operations.

The Federal Aviation Administration provided additional funding for this research.

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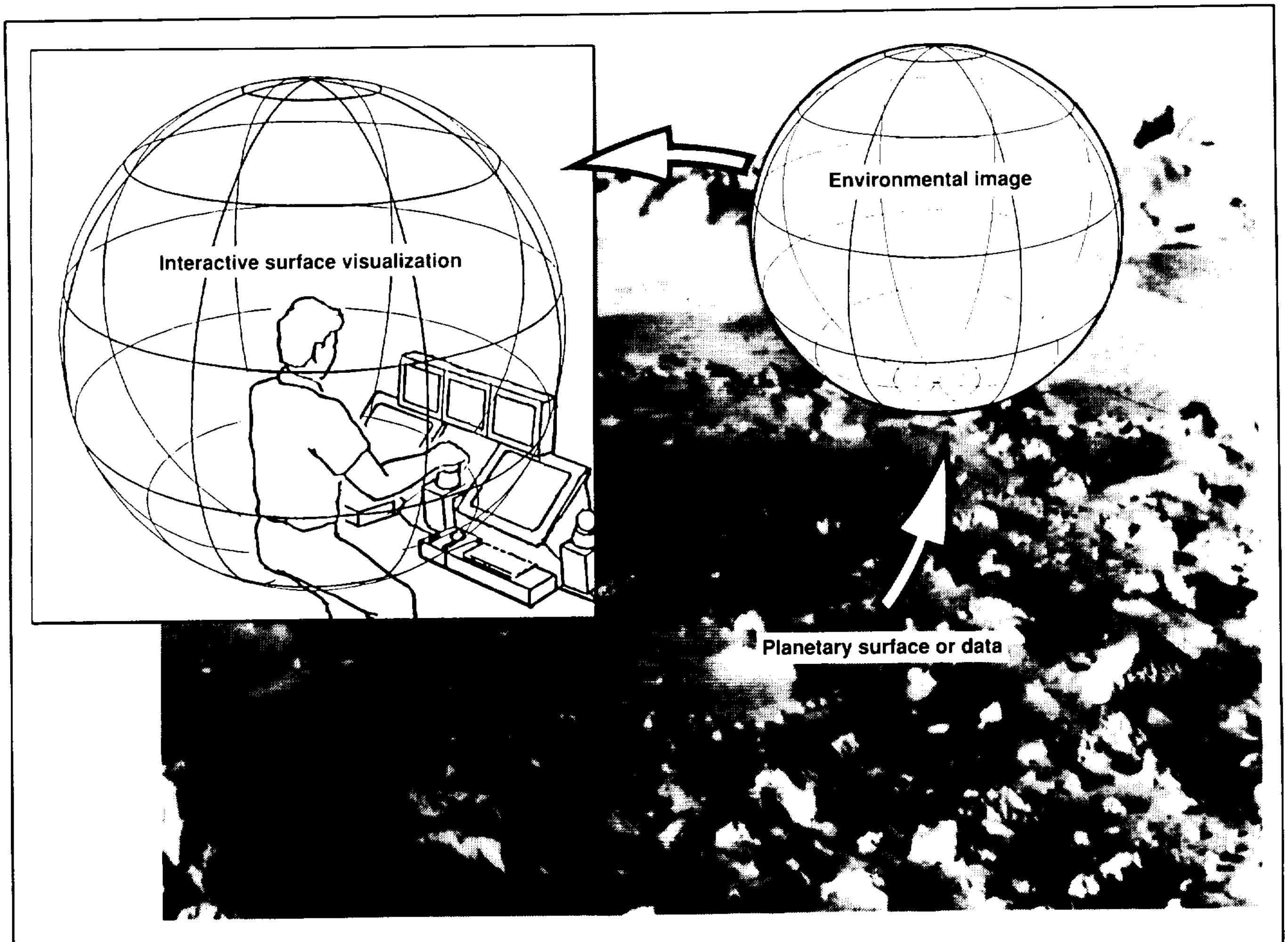
Visualization for Planetary Exploration

M. McGreevy

The Visualization for Planetary Exploration (VPE) research program is part of NASA's Pathfinder Program of research in support of its planetary exploration missions and goals. The objective of the project is to enable rapid and effective understanding of massive amounts of spatially correlated information. Effective presentation and manipulation of comprehensively integrated data, including both previously gathered data and real-time data, will allow mission investigators to efficiently survey, select, and evaluate high-payoff, scientifically interesting landing sites and rover traversal paths.

The VPE program is an interdisciplinary collaboration involving human-system interface scientists, planetary mission and science experts, and computer scientists. United States and Soviet operational experience in Lunar and planetary exploration is being reviewed with an emphasis on the methods used to visualize spatial data. Current mission plans and requirements are being analyzed with a focus



Visualization for planetary exploration

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on the human factors of planetary surface information management and scientific visualization for manned and remote exploration, and the integration of spatial data to support these interfaces.

Increasingly mission-focused human factors evaluations will be conducted to gain interface design knowledge and to refine guidelines. Methods, concepts, and strategies will be developed and validated for the management, display, and manipulation of planetary data in support of advanced visualization interfaces. These methods, concepts, and strategies will be based on mission operations and science requirements, human-computer interface principles, human exploratory behavior, and workstation capabilities.

Research and development activities focus on the augmentation of human performance by using advanced visualization interfaces for planetary exploration. Human-computer interface researchers and computer scientists are working closely with mission experts to determine key operational challenges and opportunities. Exploration mission experts will be interviewed regarding human factors issues in the use of planetary surface data. The human interface to planetary imaging data in previous exploration missions is being investigated and relevant operational experience, lessons learned, and requirements are being characterized.

Prototype workstations are being developed for human-system interface studies and technology demonstrations. The prototype systems will allow researchers to characterize human exploratory behavior relevant to planetary exploration systems. Effectiveness of prototype systems will be evaluated by analyzing human performance in the context of simulated mission tasks and environments. User strategies, interactive system modes, candidate formats, system implementation, and human-system interface design guidelines will be documented.

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Optimal Image Combination Rules for Head-Up Display

J. Mulligan

Head-up displays are often constructed by simply placing a half-silvered mirror in front of the observer without considering whether image combination by reflection (image addition) is the best that can be done. This research investigates the perceptual consequences of image combination by a variety of rules, including a multiplicative rule which might be implemented in a head-up display by means of a programmable filter (liquid crystal display).

Before it can be determined which method of image combination is "best," it is necessary to first specify what task must be performed. A number of different criteria may be specified, but one that seems sensible is that the two images should be separable by the observer; that is, the observer should be able to selectively attend to one or the other with minimal interference from the unattended image.

This problem has been approached experimentally by using random-dot patterns moving in opposite directions. Coloring of the composite patterns can be set to correspond to a variety of combination rules, and some subjects report "twinkling" or noise in addition to the two motions depicted. It is found experimentally that this noise is minimized when the patterns are combined. However, other researchers using another type of stimulus have differing results. The results have implications for theories of motion processing in the brain, in addition to the application to engineering design of head-up displays.

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Human Factors of Advanced Technology Transport Aircraft

E. Palmer, III

The purpose of this 3-year field study was to determine, by direct contact with airline pilots, instructors, and supervisors, what problems are encountered in line operations of advanced-technology aircraft. Many problems and benefits of new technology in the cockpit emerge only after obtaining extensive pilot experience in actual operations. Field studies provide a way of systematically tapping and documenting the lessons learned on the line by experienced pilots.

Two airlines participated and over 200 pilots volunteered for the study. The principal investigator, Earl Wiener (University of Miami), attended ground school and made many observation flights from the jump seat.

Results of the study show that pilots are generally very positive about the aircraft and its automatic features, but they have some reservations about safety:

1. pilots believe that automation reduces workload in routine operations, but increases it if the Flight Management System must be reprogrammed;
2. pilots are concerned that there is too much head-in-the-cockpit time;
3. pilots are concerned about degradation of their manual flying skills and take active measures to avoid it;
4. pilots believe that crew coordination is especially important in this aircraft;
5. pilots are concerned that the air traffic control system does not take advantage of the advanced navigation and guidance capabilities of the aircraft.

Additional findings from the field study on the impact of cockpit automation on crew coordination are that the traditional role definitions (such as pilot flying versus pilot not flying) often break down even though they are spelled out by the airlines' operations manual. Numerous pilots complained about a lack of clarity of "who does what," a problem usually not present in well-standardized traditional cockpits.

Supervision by the captain or the first officer may be more difficult; at the very least it may be considerably different than that in traditional two-pilot cockpits. There may be a de facto transfer of authority from the captain to the first officer because many of the first officers are more proficient than the captains on the cockpit display units which the pilots use to enter information into the flight management computers.

Pilots will often do tasks assigned to the other pilot, usually with his or her consent and awareness, for a variety of reasons. While this may at times be effective cockpit resource management, it can undercut standardization, which is the foundation of safe piloting.

A full mission simulator study is being conducted to further investigate the interaction of cockpit automation and crew coordination. The main variables in this follow-on study will be the level of cockpit automation and whether the captain is the pilot flying or the pilot not flying.

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Operator Function Modeling: Cognitive Task Analysis, Modeling, and Intelligent Aiding in Supervisory Control Systems

E. Palmer, III

This research addressed the design, implementation, and empirical evaluation of models of operator activities in the control of complex dynamic systems. The work was supported by grants from both Ames Research Center and Goddard Space Flight Center. Christine Mitchell from Georgia Institute of Technology performed the research, which included three related activities.

First, the use and development of models of operator decision-making in complex and predominantly automated space systems was studied. The operator function model (OFM) was the major tool used.

The OFM is a network model that represents how an operator might decompose control functions and coordinate the focus of attention in supervising a predominantly automated system. The network nodes in the OFM represent operator control activities hierarchically (functions, subfunctions, tasks, and actions); network arcs represent enabling conditions, such as system changes or recent operator actions.

The OFM methodology represents cognitive as well as manual actions. Physical and cognitive actions are at the lowest network level and define the model's output. The OFM can be used for cognitive task analyses of operators in complex systems.

The OFM was first used to characterize the operator activities in a Goddard ground control system, the MultiSatellite Operations Control Center (MSOCC). MSOCC is evolving into an increasingly automated system in which the operator is predominantly a passive monitor ensuring system safety and compensating for unanticipated events. Thus, understanding the new roles of the operators was a requirement for designing effective controls and displays.

Second, the OFM was used to redesign an intelligent, model-based, operator workstation for the MSOCC operator. The conventional MSOCC workstation consists of three monitors with a mixture of alpha-numeric and graphical displays. One monitor is dedicated to hardware status; one displays software status (data and error counts) at each system component; and one displays system schedule information, with individual pages for each system component and satellite.

Using the OFM, the workstation was redesigned with two monitors: one for monitoring and fault detection, and the other for fault compensation. The OFM-based workstation uses icons and graphics to support operator problem solving and fault management.

Qualitative icons depict data flow rates and error accumulations at trouble spots in the equipment networks for each satellite. Initially, the qualitative icons depict an abstract, highly aggregated view of the system; additional qualitative information about equipment networks is available upon operator request.

Context-sensitive help windows, designed and contextually controlled by the OFM, provide information for fault diagnosis. Normally required information is grouped into one display page with multiple windows. The OFM embedded in the workstation filters data for those items relevant in the current system state.

An experiment was conducted to evaluate the effectiveness of the OFM-based workstation versus the more conventional design. System performance was consistently better when the operator used the OFM-based workstation.

OFMspert (Operator Function Model Expert System), the third portion of this research, addresses the development of an operator's assistant: a stand-alone expert system that interacts with a human operator in a manner similar to a human assistant. OFMspert is an architecture for an operator's assistant that uses the OFM as its system and operator knowledge base, and a blackboard paradigm of problem solving to create a structure for updating expectations about operator activities and interpreting actual operator actions.

An experiment validated the model's intent inferencing capability and showed that OFMspert inferred the intentions of operators in ways similar both to a human expert and to operators themselves. Next, OFMspert was augmented with control capabilities. An interface allowed the operator to interact with OFMspert, delegating as much or as little control responsibility as the operator chose. Control capabilities were available at multiple levels of abstraction and allowed the operator discretion over the amount and level of delegated control.

An experiment showed that overall system performance was comparable for teams consisting of two human operators versus a human operator and OFMspert team.

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Cockpit Procedures Monitor and Error-Tolerant Systems

E. Palmer, III, C. Mitchell

The objective of this research is to develop the technology necessary for the design of error-tolerant cockpits. A key feature of error-tolerant systems is that they incorporate a model of pilot behavior. The system uses this model to track pilot actions, infer pilot intent, detect unexpected actions, and alert the crew to potential errors. In some sense, the goal is to develop an "electronic check pilot" that can intelligently monitor pilot activities.

Alternative ways to track operator activity and infer operator intent are being pursued. We are investigating techniques based on (1) a rule-based script of flight phases and procedural actions, (2) operator function models, and (3) Bayesian temporal reasoning.

The first version of the script-based program was tested against protocol data from four Boeing 727 simulator flights. The program could detect procedural errors, but its ability to account for pilot actions from procedures done out of the normal sequence was inadequate. A capability to explain unexpected actions by linking them to procedures that are nominally done or unstarted is being added to the program to remedy this problem.

Under a grant to Georgia Institute of Technology, an intent-inferencing system based on an operator function model was developed and tested on data from a satellite communications system with good results. Under a contract to Search Technology, a prototype for an intent-inferencing system based on Bayesian reasoning was developed.

In the coming year, these three methods will be compared against data from the 727 simulator. We also plan to initiate an experiment to determine how check pilots detect procedural errors and infer pilot intent.

The technology developed for the cockpit procedures monitor will be used to develop an interactive cockpit display to aid pilots in executing procedures. In its initial version, this "smart checklist" will be a graphic display of the procedural script developed to track pilot actions. Modes of checklist operation will include both passively monitoring pilot execution of procedures and automatically executing procedures.

Under a related Small Business Innovation Research contract, we will develop and test a procedure execution aid that can compose procedures that are appropriate for the current flight situation and equipment configuration. These methodologies will be used to develop and evaluate in full mission simulation a cockpit procedures monitor and a smart checklist in the Advanced Concepts Flight Simulator of the Man-Vehicle Systems Research Facility at Ames Research Center.

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Computational Models of Attention and Cognition

R. Remington

Human operators are limited in their ability to process and respond to multiple information sources. Aviation and space environments impose severe visual, auditory, and decision-making demands in situations where human failure can have catastrophic results. Information overload has been identified as a major contributor to error in military aviation, especially helicopter nap-of-the-Earth (NOE) operations, and in critical monitoring tasks such as air traffic control and ground control of space missions.

The ultimate solution to problems arising from limitations on attention and cognitive capacities will come from optimal allocation of function between human and machine, combined with optimal configuration of multimodal displays and controls. The realization of such optimization depends on a deeper understanding of attentional control. This can be achieved by developing validated computational models of human information processing.

The Human Interface Research Branch has an ongoing research program in attention and cognition focused on determining the mental resources underlying complex task performance. This research has identified stimuli that control attention and situations where distraction will be unavoidable, making it possible to design displays that better capture and direct an operator's attention.

Work on cognitive architectures has lead to models of simple multitask settings that will aid in making decisions about the use of speech controls and displays, and the allocation of tasks between the human operator and the automated subsystems. Current research will extend these findings to more complex task environments by (1) developing methods for mapping complex tasks onto underlying mental resources; (2) conceptualizing, implementing, and iteratively refining computational models of human cognition; and (3) developing mathematical models of the allocation, control, and mechanisms of human attention and performance.

Several aerospace scenarios are being investigated as a basis for analysis and model development, including (1) the NASA Test Director's task, (2) helicopter NOE and search-and-rescue operations, and (3) air traffic control and Space Station Freedom proximity operations.

The research program involves extensive in-house research and model development while it supports related modeling efforts at universities. Related efforts within the Aerospace Human Factors Research Division address interface design and evaluation, workload, methods of assuring proper levels of alertness in civil air transport, and pilot error.

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Aviation Safety Reporting System

W. Reynard, C. Billings

The Aviation Safety Reporting System (ASRS) was established in 1976. It is managed by NASA at the request of the Federal Aviation Administration (FAA) with joint NASA and FAA funding. The ASRS receives, processes, and analyzes voluntarily submitted aviation incident reports from pilots, air traffic controllers, and others. These reports describe both unsafe occurrences and hazardous situations. The ASRS offers incident reporters confidentiality and the FAA provides limited immunity for unintentional aviation safety transgressions the reporters may have committed. In exchange, the program receives safety information which can be used to remedy reported hazards, to provide data for planning and making improvements to the National Airspace System, and to conduct research on pressing safety problems. The ASRS is particularly concerned with the quality of human performance in the aviation system.

The ASRS program is unique among aviation reporting systems. Its special capabilities include

1. a proof-of-concept to acquire, analyze, and use incident data,
2. a unique methodology to capture otherwise inaccessible human performance data,
3. a one-of-a-kind data base of actual incident information as reported by the event's participants,
4. the consistent support and use of the program by government and industry,
5. a proven capability for diverse application to both research and operations,
6. the ability to actively monitor the aviation system,
7. the capability of effective technology transfer as evidenced by ASRS-type systems in other countries and disciplines.

In addition to screening and processing report receipts for entry in the data base, the ASRS maintains the data base and supporting computer hardware and software and integrates the data base to satisfy information requirements of both government and industry organizations. Report receipts can be statistically analyzed for trends and problem concentrations—although there are important theoretical limitations on the use of ASRS data for this purpose. Since its inception, the ASRS has published numerous research studies based on its data, covering the full spectrum of aviation activity; in addition, the program issues alerting messages and responds to special data requests.

The ASRS currently operates under a Memorandum of Agreement with the FAA effective until September 1992. The program has achieved a productive and active rapport with FAA operational and research organizations and is consistently used by NASA, National Transportation Safety Board, Department of Defense, and the aviation community.

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Interactive Descent Advisor Tutorial Project

R. Roske-Hofstrand

As part of ongoing air traffic control (ATC) human factors research, development has begun on a Hypercard-based interactive tutorial system that allows controllers to become familiar with new automation tools prior to their use in full simulation environments. Controllers from the Denver Terminal Radar Approach Control (TRACON) Facility participated in familiarization sessions with the Interactive Descent Advisor (IDAT). The IDAT is implemented on a Macintosh computer and records data for evaluating the rate of learning to operate the new tools.

The controllers were able to use previously unfamiliar ATC tools in the full simulation runs in much less time than was possible without IDAT. In addition, IDAT served as a rapid prototyping environment for many of the automation tools, as well as a dynamic documentation data base for tool development. The tutorial decreases the amount of time necessary to exercise the automation tools, and it establishes a model for addressing design and training issues simultaneously.

Interactive tutorial runs provide timely and important human factors information which can be used by developers of controller aids and display formats. Results of current studies will be used to develop a comprehensively structured tutorial system making use of new available technologies such as voice output, scanner/digitizer, and SuperCard Software.

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Portable Life Support Systems Technology

B. Webbon, W. Lomax

Current research and development programs are investigating various aspects of the technology and subsystems that will be required for portable life support systems (PLSS) on future missions such as Lunar and Mars explorations.

Initial efforts focused on developing automatic control systems for advanced PLSS to improve crew task performance, to increase comfort, and to reduce the size of the PLSS by providing a more efficient system that will adjust the system's operating parameters to the astronaut's instantaneous requirements for life support. An instrumented 0-g exercise simulation facility was developed to acquire the data needed to develop and test new control concepts.

Other efforts are under way to develop advanced concepts for PLSS thermal control systems. Heat storage systems, such as fusible heat sinks using high heat capacity materials, and heat rejection systems that incorporate advanced thermodynamic refrigeration cycles are being investigated.

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Thermal Control Coatings for Space Suits

B. Webbon, B. Squire

The Shuttle Extravehicular Mobility Unit and past suit configurations for Apollo and Skylab have used the Integrated Thermal Micrometeoroid Garment (ITMG) to provide thermal protection to astronauts performing extravehicular activity (EVA). The ITMG is a multilayer garment that lessens the incident thermal radiation. Several characteristics limit its practicality for a routine space station EVA, including restricted mobility, complex fabrication, relatively low resistance to atomic oxygen degradation and orbital debris penetration, and a limited lifetime.

The no-prebreathing requirement for space station EVA operations has led to the development and evaluation of hard space suits. The hard suit structure allows designers to provide passive thermal control to the suit structure. Environmental influence on the suit can be minimized with a high-reflectance coating.

Materials testing on 10 candidate metal coatings was completed. Both polished and textured substrate surfaces were investigated. Samples underwent corrosion and abrasion tests with subsequent determination of optical properties to quantify degradation. Additional testing included tape adhesion tests, salt spray fog, and thermal soak.

The plated gold coating on a polished surface exhibited consistently higher reflectance throughout the test protocol. Two suit elements were plated with gold and will be instrumented for use in a thermal vacuum test. The test article will contain a pressurized, temperature-controlled, annular gas flow (to simulate ventilation in a suit limb) and will be subjected to simulated components of the space station EVA thermal environment.

Data from the test will be used to validate a finite element computer model of the suit parts in the same environments. Preliminary analyses of the suit elements with a graybody reflectance of 98% in a cold environment (radiation to deep space only) yield structural temperatures of 68.3° F. Convective heating in this cold case is 2.25 Btu/hr-ft^2. Addition of direct incident solar radiation raises equilibrium temperatures to 71° F. Convective cooling is 1.36 Btu/hr-ft^2. These heating/cooling loads are lower than for past and current suit insulation. The high-reflectance coating isolates the suit from its thermal environment.

The model will be revised so it will include infrared radiation sources. Infrared radiation will be a significant component of the thermal environment in some space station EVA scenarios. After validation of the model with empirical data, several realistic configurations will be analyzed by parametrically varying the model interior convection, suit-coating reflectance, and space environment. The model may be adapted for use in research of other thermal environments, such as the Lunar or Martian surfaces.

A detailed analysis of the AX-5 suit using coatings for thermal control has confirmed the validity of this approach.

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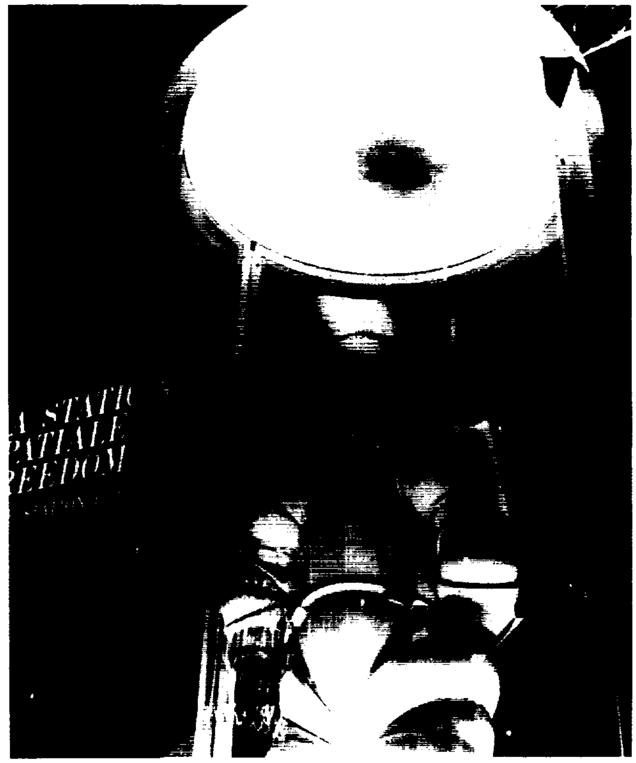

AX-5 space suit on display at the Paris Air Show, June 1989

Advanced EVA Suit Technology

H. Vykukal

Ames Research Center has an ongoing program to address extravehicular activity (EVA) suit technology requirements for Space Station Freedom and exploration missions. A product of this effort has been the development of the AX-5 space suit. Overall objectives of this program have been to provide a high-mobility suit technology that eliminates the need for prebreathing, provides increased hardware and systems life, minimizes maintenance, provides increased hazard protection, and accommodates a wide range of sizes.

As a part of the overall evaluation process, a series of tests has been established at the Johnson Space Center (JSC) to assess the performance of advanced suit concepts as compared to the current Shuttle Extravehicular Mobility Unit (EMU). These tests consist of mobility range comparisons, torque/force work capability, general workstation performance assessment, and the EASE/ACCESS structure assembly simulation.

In early 1988, tests of the AX-5 mobility and range-of-motion were completed in the JSC Weightless Environment Test Facility. Although JSC has not yet released the hard data of these tests, indications are that the AX-5 has considerably more mobility than the Shuttle EMU.

The AX-5 bearing assemblies have been modified and were successfully tested. The component mobility, torque, and life cycle tests performed at Ames completed the performance assessment of the AX-5. Subsequent upgrades are anticipated and will be incorporated into the AX-5.

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Auditory Display Systems Research

E. Wenzel

Auditory cues can provide a critical channel of information in complex spatial environments; during periods of high visual workload; and when visual cues are limited, degraded, or absent. Some or all of these conditions will be present in such space station operations as (1) the monitoring and control of autonomous and semi-autonomous telerobots, (2) the conduct of extravehicular activity (EVA) and the use of visor displays, and (3) the management of complex on-board space station systems. Auditory information can also enhance the utility of virtual environment displays, such as NASA's Virtual Workstation.

Spatial auditory displays require the ability to generate localized sound cues in a flexible and dynamic manner. Ames Research Center, with additional Office of Naval Research funding, is investigating the underlying perceptual principles of auditory displays and is also developing an advanced signal processor based on these principles. Rather than using a spherical array of speakers, the prototype maximizes portability by synthetically generating three-dimensional sound cues in real time for delivery through earphones. Unlike conventional stereo, sources will be perceived outside the head at discrete distances and directions from the listener. This is made possible by numerically modeling the effects of the outer ears (the pinnae) on the sounds perceived at various spatial locations. These "pinnae transform filters" can then be applied to arbitrary sounds (voices, for example) to cause them to seem spatially located.

A nondirectional audio display, based on well-established electronic sound synthesis standards, is also being developed. An initial version of an auditory symbol editor was completed in 1989. This system will enable researchers to investigate auditory symbology for communication of meaning apart from verbal content. In addition, experience in the integration of this system with the Virtual Workstation will benefit the later incorporation of the spatial auditory display system.

Cooperative research with Dr. Frederic Wightman of the University of Wisconsin, Madison, is under way. This research includes perceptual validation of the synthesis technique in both practical and more basic areas. Practical issues include required computational resolution and signal bandwidth. Basic issues include acoustic determinants of individual differences in localization behavior. In 1989, a prototype version, real-time signal processor (the "convolvotron") was fabricated and is being converted to a printed circuit (PC) board for greater reliability and ease of replication. A PC board capable of synthesizing four localized sources is now available.

Plans include refinement of Dr. Wightman's measurements of the pinnae transform filters for use in the convolvotron and evaluation of the perceptual validity of the convolvotron-generated directional audio for the general population of listeners. The convolvotron is being incorporated into the Ames Virtual Workstation and will undergo system calibration and performance evaluation in specific applications. Replications of the convolvotron will also be fabricated for interface evaluation in other applied contexts in collaboration with the Rotorcraft Human Factors and Aviation Systems Research branches.

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Rotorcraft Flight Dynamics Math Model Development

R. Chen, M. Takahashi, M. Ballin, N. Mansour

Current real-time rotorcraft models, General Helicopter and Army Helicopter (GENHEL and ARMCOP), do not accurately represent the high-order dynamics for modern rotors. The development of these models is a prerequisite to examining strategies for enhancing maneuverability and agility for rotorcraft because the fundamental limitations arise from the rotor dynamics and resulting loads. Consequently, it is necessary to develop rotorcraft mathematical models of sufficiently high order and fidelity to capture the dynamics of interest for design of high-order, high-gain control systems aimed at enhancing agility and maneuverability.

A requirement is the development of such models that can operate in real time and thereby serve as the basis for ground simulation investigation of the developed technologies. For the real-time model, the approach has been to develop, in-house, a new real-time rotor General Blade Element Rotor (GBER) module which correctly represents, for the first time, arbitrary hinge sequences.

This module is then configured to represent either the UH-60 rotor for inclusion into GENHEL, which is a contractor-developed UH-60 math model, or the AH-64 rotor for inclusion into Fly Real Time (FLYRT), which is a contractor-developed AH-64 model.

The GBER rotor module has been configured to represent the UH-60 and has been implemented into GENHEL. In addition, the contractor updated and improved GENHEL. These improvements have been evaluated in a simulation validation experiment on the vertical motion simulator. The improved GENHEL, without GBER, is operating in a simulation validation experiment. GBER has been checked and is ready to be incorporated into GENHEL as a new rotor module. Also, a new fuselage module, appropriate to the AH-64, has been developed and is available for incorporation into FLYRT.

A non-real-time UH-60 model, MARC-I, has been developed to complement these real-time models, and has been validated against UH-60 flight and GENHEL data. This model incorporates blade twist degrees of freedom and additional air-mass degrees of freedom. It can be used to examine the effects of torsional flexibility on the stability and control of hingeless and bearingless rotor helicopters, such as the Light Helicopter Experimental (LHX) or the High Maneuverability and Agility Rotor and Control System (HIMARCS) rotor. MARC-I has been verified against UH-60 data, and is in the final "clean-up" process.

Plans are to develop agility and maneuverability design requirements using a "perfect" helicopter, and then to use the models developed here to evaluate control requirements.

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Helicopter Nap-of-the-Earth Obstacle-Avoidance Guidance

V. Cheng, B. Sridhar

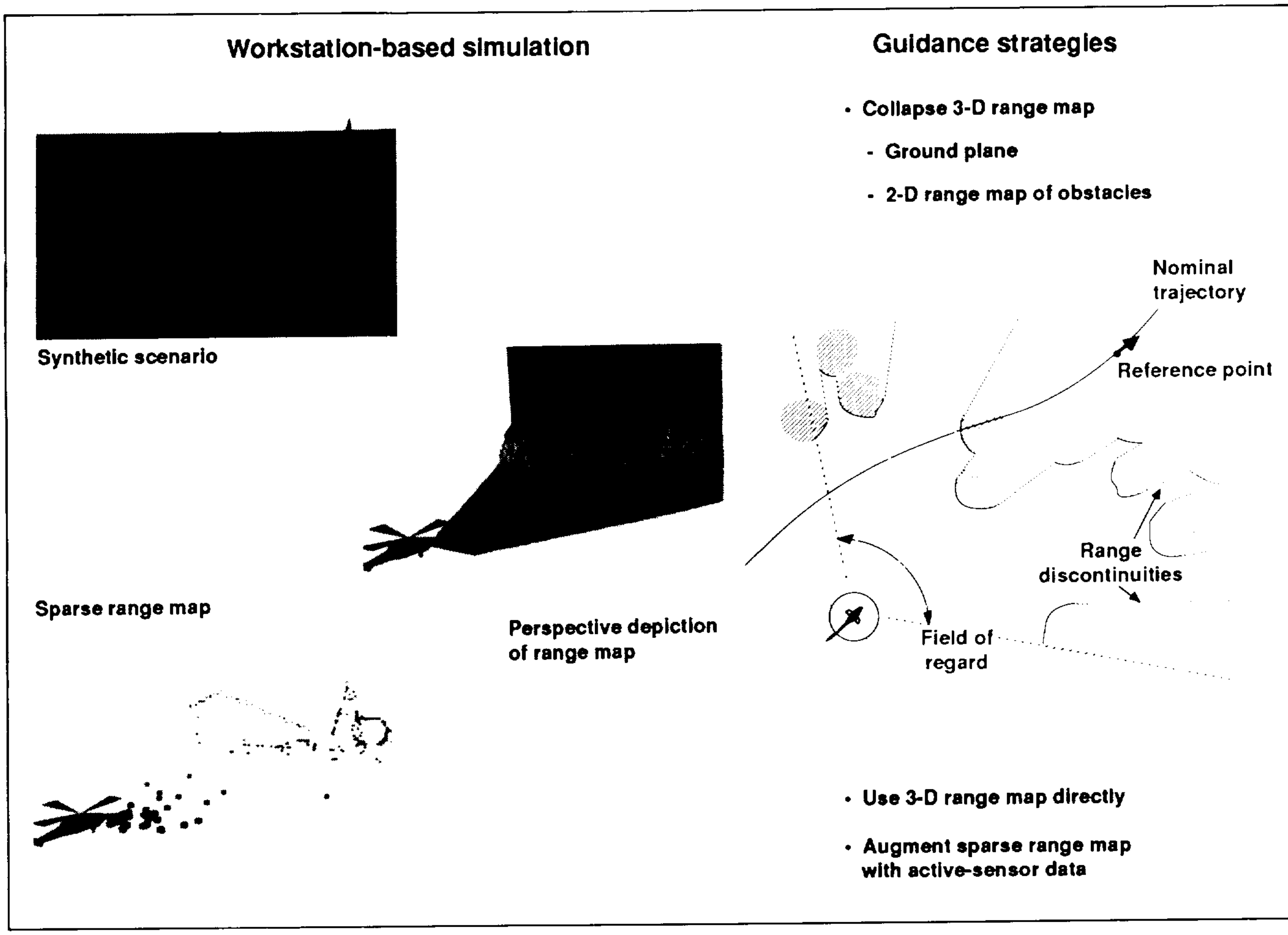
Obstacle avoidance is the most critical function of the automatic guidance structure conceived for nap-of-the-Earth (NOE) rotorcraft flight. It represents the only guidance function that uses on-line information from the outside world provided by the obstacle-detection subsystem. The current effort is to develop automatic obstacle-avoidance guidance, which will constitute the core guidance function of a more flexible pilot-directed guidance system planned for the program. Because of the heuristic nature of the conceived guidance techniques, computer simulations with three-dimensional (3-D) graphics are needed for evaluation and verification.

Various concepts for performing obstacle-avoidance guidance were proposed and documented in a paper presented at the 1989 American Control Conference. The previous two-dimensional (2-D) obstacle-avoidance concept made use of discontinuities in the range map, presumably available from the obstacle-detection module, to identify a number of potential openings worthy of further evaluation. Efforts to extend this concept to the full 3-D scenario fall into two alternatives: (1) identify discontinuities directly in the 3-D range map, or (2) compress the 3-D range map into a terrain surface for vertical path following and a 2-D range map for flight path selection over the terrain surface.

Some software has been developed for studying these alternatives. In addition, consideration of state-of-the-art obstacle-detection techniques suggests that availability of full range maps may not be a realistic assumption.

A more likely situation is that only sparse range maps can be produced by a passive sensor, which has to be augmented with an active sensor. An integrated design has been proposed and it calls for the obstacle-avoidance module to issue commands to drive the active sensor selectively. Because of the asynchronous operations between the two sensors, a data base other than the body-relative range map has to be maintained for data fusion.

Extension of the 2-D obstacle-avoidance concept to 3-D addresses the basic obstacle-avoidance problem under the most favorable condition that a full range map is available. Tests of the techniques with synthetic scenario and range maps have shown that both alternatives are plausible. However, to discriminate range variation between the azimuth and elevation directions, the sensors have to operate with roll position fixed, and even with pitch position fixed under the second alternative. With the integrated obstacle-detection/avoidance system using hybrid passive/active sensors, range data have to be transformed into a uniform data base for data fusion. Although the transformation requires additional processing, the data base also lends itself to accumulation of data over time and fusion with on-board prestored terrain data.



Pilot-directed guidance for obstacle avoidance

As illustrated in the figure, a 3-D simulation with solid-model graphics is being developed on a Silicon Graphics, Inc., IRIS 4D/220GTX graphics workstation. Obstacle-avoidance guidance software and software for simulating the obstacle-detection subsystem will be developed and evaluated with the simulation.

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AD100 Integration and Operation

A. Cook

The first of the Ames Research Center's SimLab replacement computers was delivered and a 90-day acceptance test was completed. An intense project began so the system would be operational within 6 months of acceptance. Tests demonstrated a fully operational rotorcraft (Blackhawk) simulation on the Vertical Motion Simulator (VMS), complete with motion, visual displays, and cockpit controls. This represented the final proof testing of the system in January 1989.

In a report published by the manufacturer, it was stated, "A fact worth noting about the Ames installation was the speed at which the NASA engineers got their SYSTEM 100 up and running. This is especially noteworthy given the I/O task they had to accomplish. The Ames application required a high degree of interaction with the model, combined with a need to maintain flexibility."

The first scheduled operational simulations using the AD100 began in June 1989. These were two concurrent simulation investigations: a UH-60 evaluation on one shift and a Rotorcraft Aircrew Systems Concept Airborne Laboratory (RASCAL) investigation on the other shift.

The AD100 system offers Ames SimLab a considerable increase in computational performance over earlier, obsolete machines. It was chosen following a rigorous selection process, which included a benchmark based on implementation and execution of a large rotorcraft model.

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C-17 Direct Delivery Airlifter

A. Cook

A simulation of the U.S. Air Force C-17 was conducted on Ames Research Center's Vertical Motion Simulator (VMS), requested by the Air Force and supported by the Douglas Aircraft Company. The purpose of the investigation was to explore the handling qualities and flight dynamics of the Short Take Off and Landing transport design of Douglas, before the design freeze and the construction of the first aircraft. Both the Air Force and Douglas viewed the investigation as very successful.

A singular benefit of large-amplitude motion simulation was identified during these investigations. Sharp lateral control inputs resulting in rapid roll oscillations cause pilot roll input to the control stick.

U.S. Air Force C-17 direct delivery airlifter

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The C-17 has a "fighter-type" force control stick, rather than the conventional transport aircraft column/wheel. These inadvertent pilot roll inputs become coupled to the aircraft roll motion and result in a form of pilot-induced oscillation. This design anomaly was not discovered before VMS motion simulation, and it underscores the value of such simulation capability during aircraft development.

Planning and design changes are under way at Douglas to resolve this flight control problem. Additional entries of the C-17 in the VMS are scheduled.

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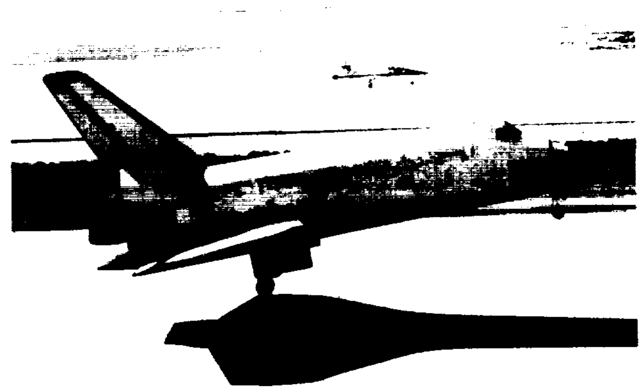

Space Shuttle Columbia

Vertical Motion Simulator Space Shuttle Approach and Landing Simulation

A. Cook

Space Shuttle orbiter simulation on the Vertical Motion Simulator (VMS) investigated landing/rollout issues relative to touchdown, steering, braking, deceleration, tire failures, and cross-wind landings. Specific items investigated included: (1) General Purpose Computer/Nose Wheel Steering (GPC/NWS) control laws for heavy weight vehicles, (2) drag chute design and transients from hardware tests, (3) tire wear at John F. Kennedy Space Center runway, (4) carbon/carbon (versus beryllium) brakes with antiskid system, and (5) crew evaluations.

While this simulation was in progress, Space Shuttle Columbia (STS-30) returned from orbit and landed at Edwards Air Force Base. During Columbia's landing a control problem occurred at the initiation of nose-wheel-steering (NWS) because of strong gusting crosswinds. Subsequently, the available gust profile data from the STS-30 landing was gathered and coded into the ongoing VMS simulation. Within 11 days of the STS-30 landing, pilots were flying the VMS with a reconstruction of the encountered conditions.

During the landing simulation, the NWS problem was discovered as a function of the enabling of NWS following weight-on-nose-gear (WONG). At that point the nose wheel was in caster-mode, at an angle to the body axis, due to the residual yaw angle because of the crosswinds. The initializing logic for NWS caused the nose wheel to center on the body X-axis, which caused a sudden directional control problem for the pilots.

An engineering solution to the problem was developed during the simulation, that included a change in NWS initiation delay from 0.48 seconds to 3.2 seconds following WONG and a change in NWS initial position from zero to "current" (or feedback) position. These changes were then evaluated by 39 astronauts and submitted to the Lyndon B. Johnson Space Center Program Review Changes Board and approved for incorporation into the next shuttle flight (STS-28). All this was accomplished in a little over 4 weeks following the STS-30 landing, while the VMS simulation was in progress. During the 6-week simulation investigation, 2018 landings were performed for data and over 2500 landings were conducted.

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Analysis of Records from Four Airliners in the Denver Microburst

R. Coppenbarger, R. Wingrove

Ames Research Center, in cooperation with Langley Research Center, the National Center for Atmospheric Research, and the Federal Aviation Administration, has begun an effort to determine the nature, cause, and extent of wind-shear hazards through a detailed analysis of the flight records of four airliners that encountered microburst activity at Denver, Colorado, July 11, 1988. The data set available from this incident is unique because it includes flight records from multiple aircraft along with data from a prototype Doppler weather radar system. In addition, meteorological soundings, taken before the incident, were used to begin a numerical simulation of the microburst.

The initial goal of this research is to derive horizontal winds from flight data analyses and to compare and augment these results with data from Doppler radar and the numerical model.

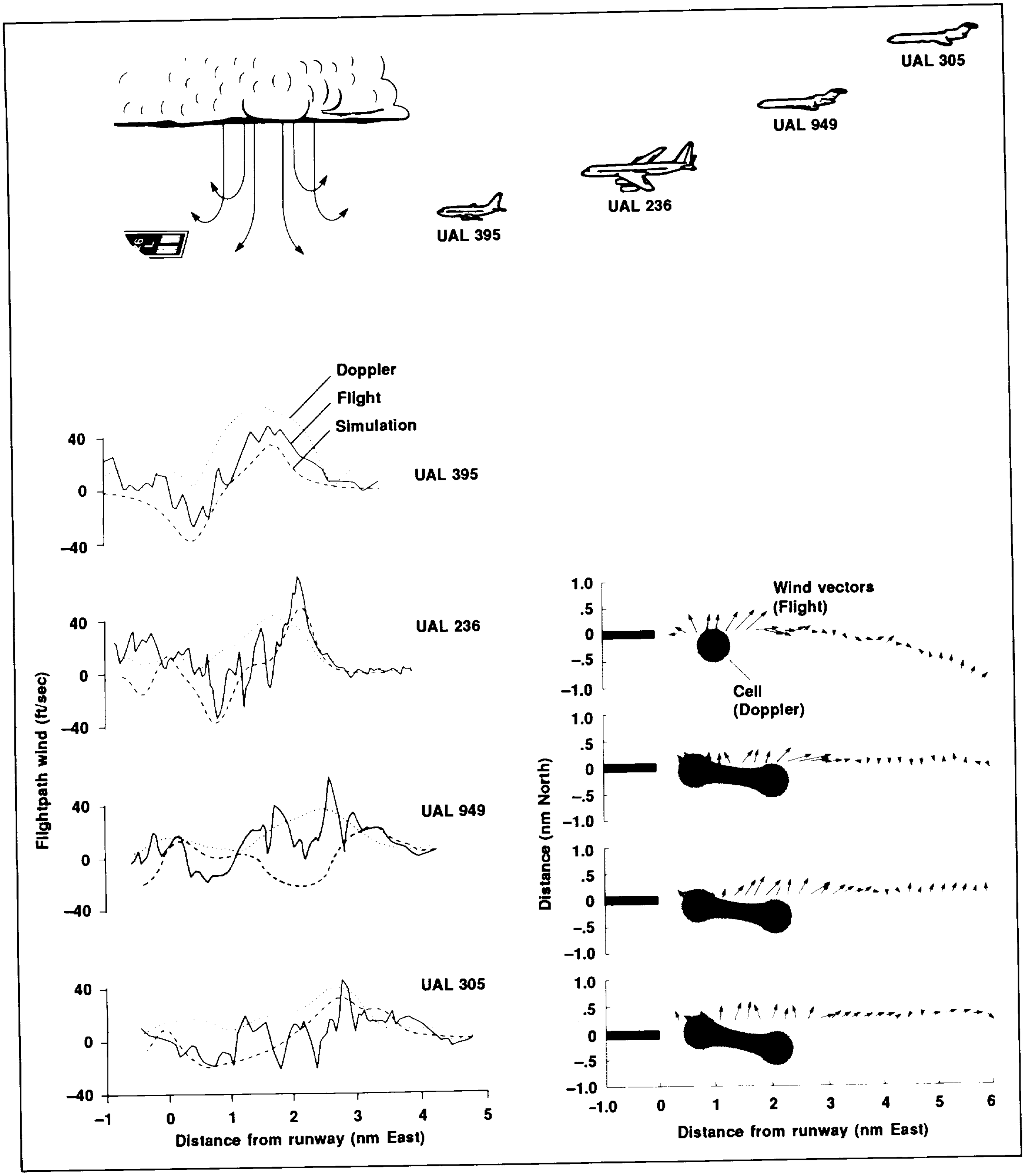
Air traffic control radar position data are used to derive horizontal winds from the flight records. Inertial speed is determined from the radar data, and the aircraft speed with respect to the air mass is determined from the flight recorder data. The differences between the two represent the winds along the aircraft flightpath.

The four encounters provide information about the time-varying changes in the strength, size, and location of the microburst. As illustrated in the figure, the results show significant expansion in the size of the microburst and indicate the existence of internal velocity fluctuations. The second aircraft encountered a headwind-to-tailwind change of 115 feet per second, which is the largest for all four aircraft. The developing wind pattern measured from the aircraft is in general agreement with the measurements from Doppler radar and the analytical results from the numerical simulation.

The aircraft data complement these other findings by providing a more detailed analysis of the internal velocity fluctuations within the microburst. The Doppler data indicate that a second cell developed within the microburst at some time between the first and second aircraft encounters. This observation appears to be consistent with the wind vectors determined from the flight data. Furthermore, the velocity fluctuations experienced by the last three aircraft appear to have resulted from the two adjacent cells.

The Ames-derived estimates of the winds from the flight records on board the four airliners provide a new, detailed description of the turbulent wind environment in a severe microburst. The results show significant expansion in the size of the microburst and indicate internal velocity fluctuations that were apparently caused by multiple cells in the microburst. These findings will aid in the modeling of severe microbursts.

Future emphasis will be on the modeling of dynamic flow fields with multicell and vortex-induced turbulence and associated effects on aircraft operating problems.



Analysis of flight records from four airliners in the Denver microburst

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Final Approach Spacing Tool

T. Davis

The Advanced Air Traffic Control Concepts simulation has been expanded to include Terminal Radar Approach Control Facility (TRACON) operations and an automation aid referred to as the Final Approach Spacing Tool (FAST). FAST assists TRACON controllers in sequencing and spacing arrival aircraft for maximum runway throughput.

The concept is based on monitoring each aircraft's current state (position, airspeed, and heading) and predicting arrival time based on a nominal four-dimensional (4-D) path to the runway, the aircraft's performance characteristics, and current weather conditions. Based on a conflict-free scheduled arrival time at the runway, an efficient path to the runway is synthesized using speed control, path stretching, and path modification. The suggested path and speed commands are displayed to the controller using mouse-based functions and a color graphics interface.

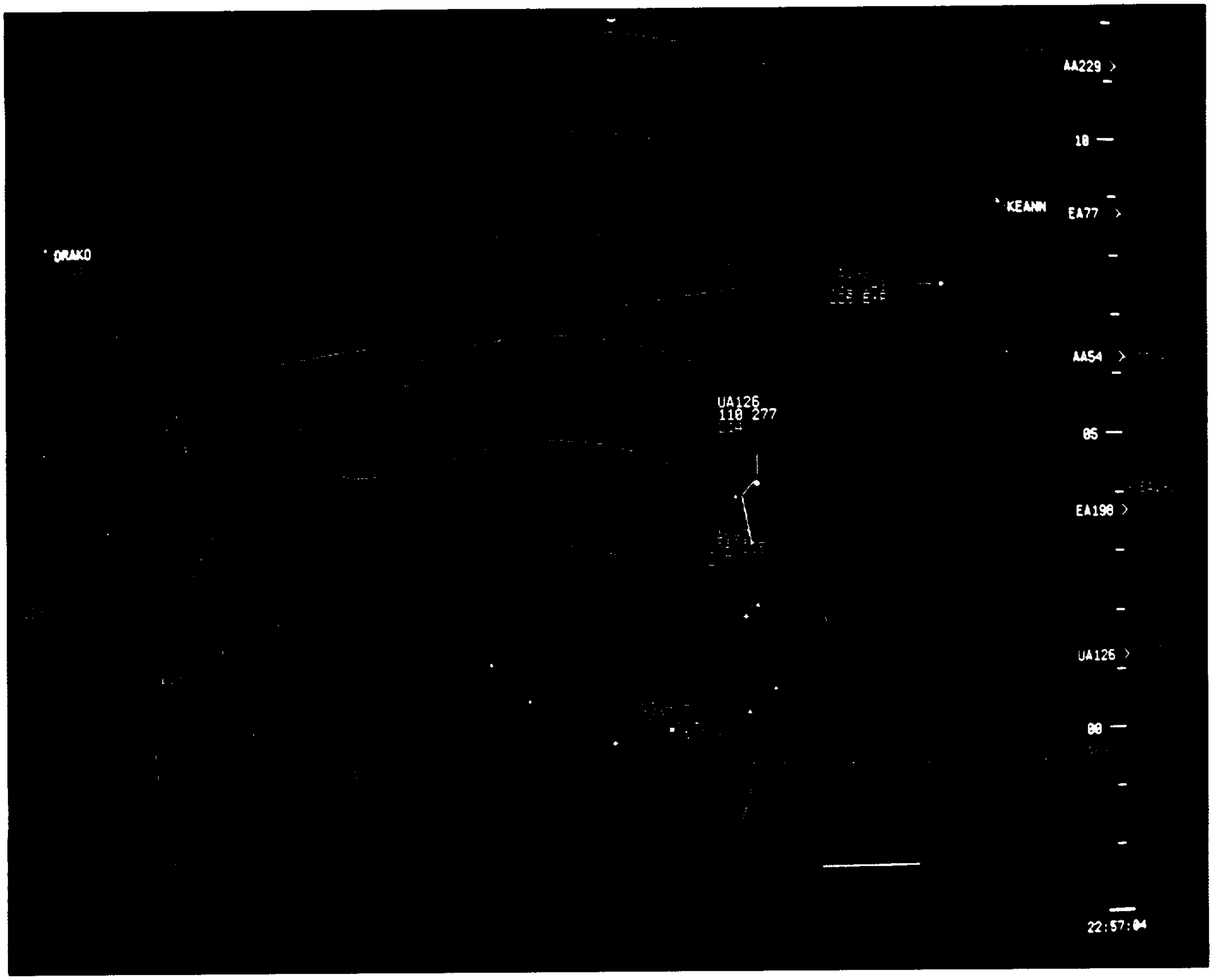
A simulation capability of the Denver TRACON was developed and integrated with the existing Air Route Traffic Control Center (ARTCC) simulation facility. Several major components of FAST have been completed. These include a trajectory synthesis algorithm which makes predictions of aircraft arrival times based on aircraft performance and weather conditions, off-route vectoring advisory capability, rescheduling for arrival position shifts within the TRACON, missed approach advisory capability, an interactive controller graphical interface, a graphical timeline for display of arrival sequence, and communication links and protocols to the traffic manager and ARTCC controller displays.

The FAST has been implemented to fully use the mouse and graphical display output capabilities made possible by the high-powered computer graphics workstations to allow uninhibited communication between the controller and the automation tools.

A candidate display incorporating the FAST features is shown in the figure. The tool was integrated with the Traffic Management Advisor and Descent Advisor Tools in the March 1989 simulation and was shown to be an effective aid for the TRACON controller. The controllers enthusiastically supported the concept and rated the system favorably.

Development of a TRACON simulation greatly enhances the advanced air traffic control simulation capability. It allows the test and evaluation of controller automation aids for the TRACON. It also allows the effects of automation tools designed for the ARTCC (descent advisor) and Traffic Manager on TRACON operations to be evaluated.

A follow-on simulation is scheduled. This simulation will include Langley Research Center's 4-D-equipped TSRV 737 simulator. Further development of FAST will include the capability for advisory information on missed approaches and enhanced graphical presentation of advisories. Live traffic evaluations are being planned for 1991.



Display of the final approach spacing tool

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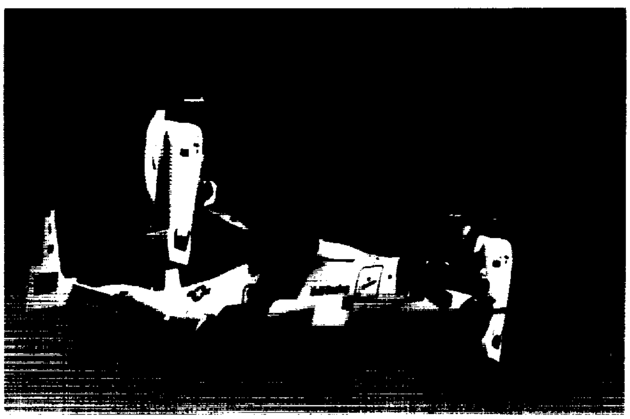
MV-22 Tilt-Rotor Simulation

W. Decker

As part of the recent NASA/Navy Memorandum of Understanding on tilt-rotor technology, a joint project was initiated among the U.S. Marine Corps, U.S. Navy, and NASA to investigate maneuver and control requirements for a tilt-rotor aircraft engaged in one-versus-one air combat with a fixed-wing aircraft or helicopter. A group-based simulation was conducted, which included transport or agile armed-escort tilt-rotor opposed by a fixed-wing aircraft or helicopter, simple missile and gun models, and maneuver-within-terrain environment.



MV-22 tilt-rotor aircraft

The tilt rotor was mechanized in one fixed-base cab with the opponent mechanized in a second fixed-based cab. Two tilt-rotor configurations were simulated: a transport aircraft similar to the V-22, and a conceptual design for an agile armed-escort aircraft. Over 800 evaluation runs were flown by pilots from the Marines, Navy, and Bell Helicopter with support by the Ames Research Center research pilots.

The ground-based simulation provided the Marines with an early look at operational issues and provided data needed to develop a draft V-22 operations manual. In addition, the operational focus of the simulation experiment provided the NASA/Navy/industry team with an understanding of tilt-rotor air combat maneuver and flight control issues requiring further development.

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Satellite-Based Navigation

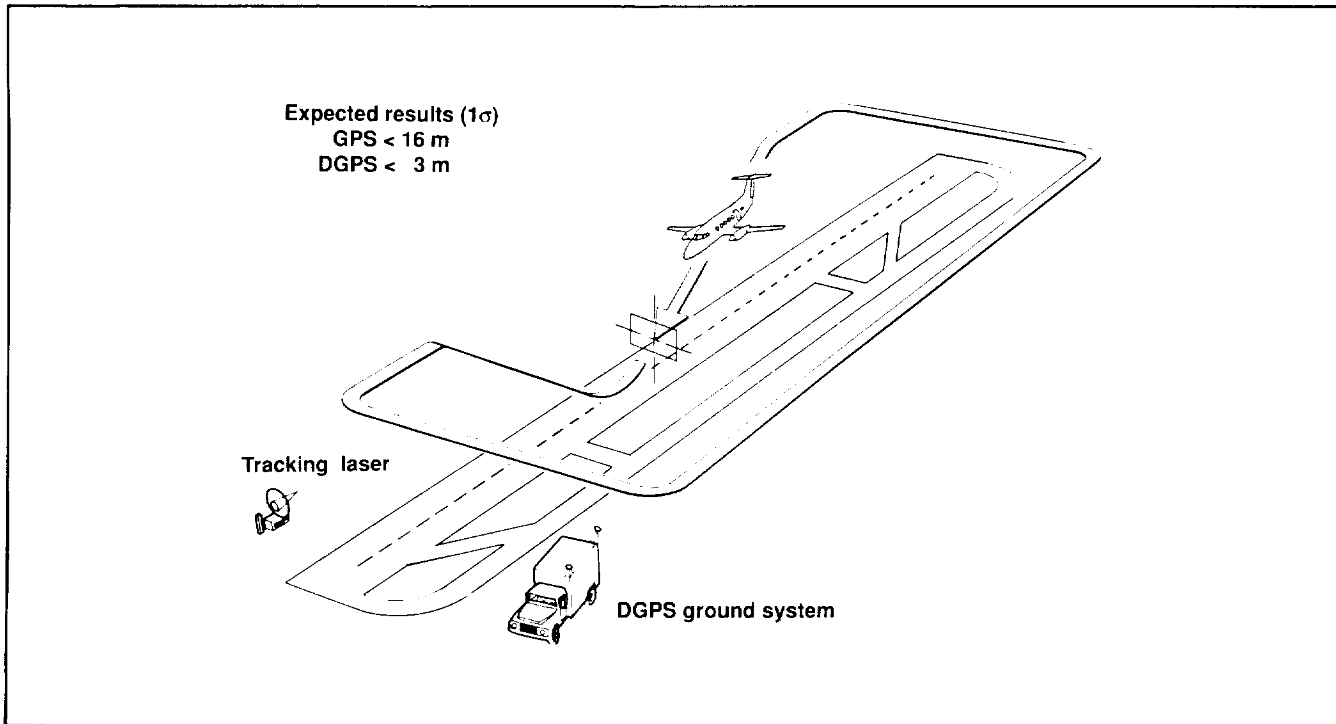
F. Edwards

A joint program has been initiated with the Department of Defense (DOD) and the Federal Aviation Administration (FAA) to evaluate the use of the Precision code NAVSTAR Global Positioning System (GPS) to support terminal area operations.

The program builds on the theoretical and experimental studies conducted under the Rotorcraft Differential GPS (DGPS) Program which used the civil code. The program will select an appropriate configuration for both the ground reference system and the flight system to evaluate the performance through simulation and ground and flight testing.

The DOD and NASA signed a Memorandum of Agreement (MOA) to cooperate on the joint project and provide equipment, funds, and personnel. The FAA tentatively offered to supply funds and planning, and the arrangement is being formalized.

The DOD has delivered two 5-channel GPS receivers to NASA for integration in the airborne and ground DGPS and two ring-laser gyro inertial navigation system units. The receivers were installed in the laboratory and are being tested in a static configuration. A study contract was completed to define the research hardware configuration and the software requirements specification for the airborne, ground, and laboratory system which will be used in the program.



Terminal approach operations with NAVSTAR GPS

The DGPS is a particularly attractive alternative mechanization of GPS which provides significant improvements in performance when compared to conventional GPS. The additional performance obtained may prove sufficient to support autonomous low-altitude flight, instrument approach and landing, weapons delivery, and air drops into areas not currently served by ground-based guidance aids.

Future plans include: (1) completion of the detailed software design and initiation of the software development; (2) acquisition and integration of the components for the airborne, ground, and laboratory research systems; and (3) negotiation of an MOA with the FAA to establish future program requirements and to secure program funding.

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Traffic Management Advisor

H. Erzberger, W. Nedell

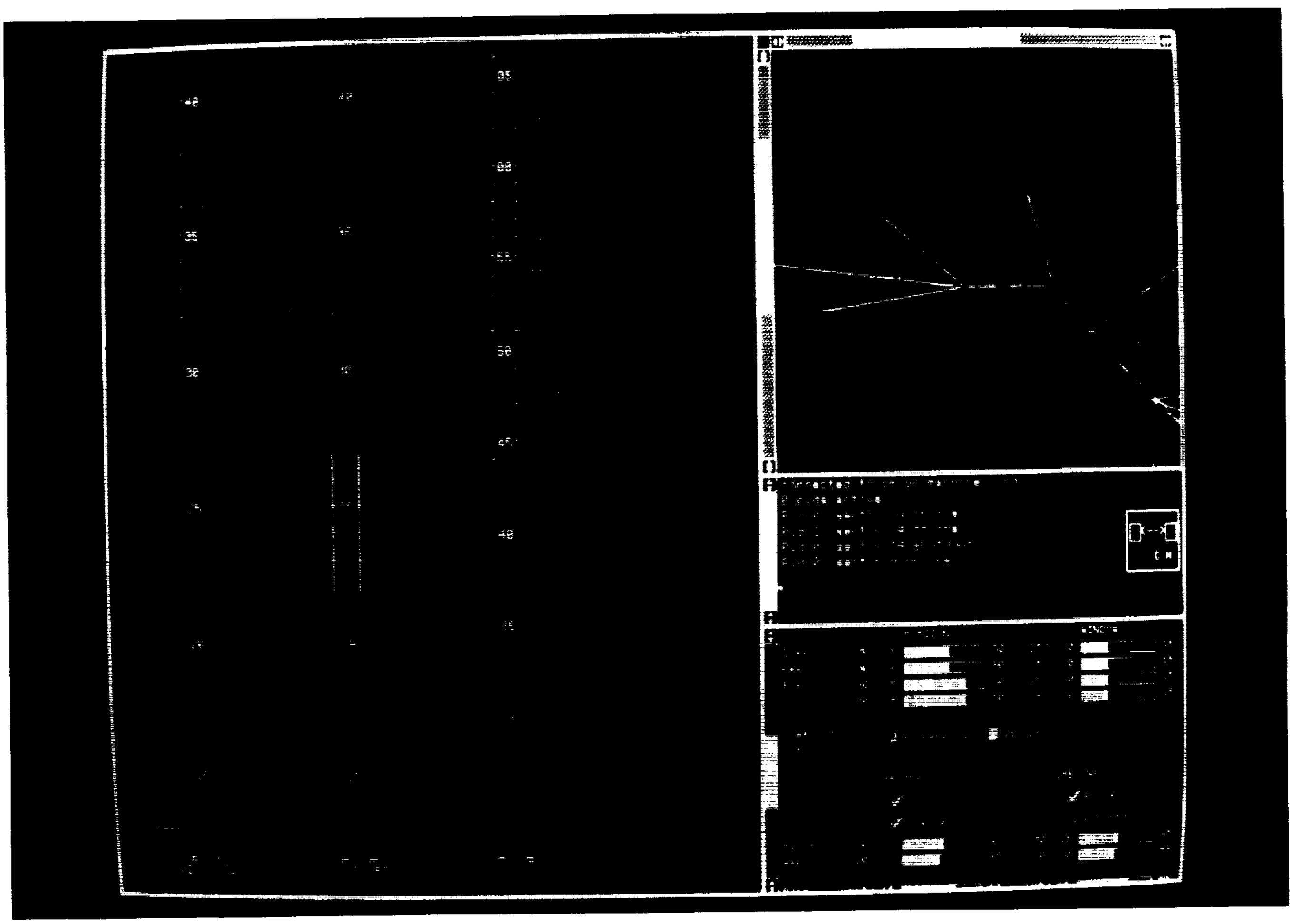
The Traffic Management Advisor (TMA) aids the air traffic flow controller in coordinating flights from multiple sectors through the generation of efficient landing schedules. The TMA includes algorithms, a graphical interface, and interactive tools for use by the Center traffic manager or Terminal Radar Approach Control Facility (TRACON) controllers in managing the flow of traffic within the terminal area.

The primary algorithm incorporated in the TMA is a real-time scheduler that generates efficient landing sequences and landing times for arrivals within about 200 nautical miles from touchdown. Its graphical interface and interactive tools are designed to assist the traffic manager in monitoring the automatically generated landing schedules, to override the automatic scheduler with manual inputs, and to change scheduling parameters in real time.

The TMA has been implemented on a separate workstation that is interfaced with the workstations running the descent advisors (DA) at the various arrival areas. In essence, the scheduler is a real-time algorithm that transforms sequences of estimated times of arrival (ETA) into reordered sequences of scheduled times of arrival (STA) using one of several scheduling protocols selected by the traffic manager. Operation in real time implies that the algorithm generates the STAs in a small fraction of the time it takes each aircraft to fly from its initial position to touchdown.

One possible display configuration is illustrated in the figure. In the window on the left are three timelines. The first displays the STAs generated by the TMA. These scheduled times are sent to the appropriate arrival sector. The second and third lines provide ETAs.

The window on the upper right gives an overview of traffic in the Center. The middle window gives the status of all DAs providing ETA data to and receiving STA data from the TMA. The window on the lower right acts as the traffic manager's control panel where various scheduling parameters, such as



Display of traffic management advisor

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the airport acceptance rate and the configuration of the time-lines, are selected by mouse-actuated switches and sliders as well as keyboard entries.

The TMA was included in the March 1989 simulation. The algorithms provided efficient schedules that were used as a basis by the sector controllers in managing traffic within the individual sectors.

The TMA is an essential element of a computer-aided ATC flow management system. It provides the means for overall coordination of traffic in the terminal area. The display permits the controller to review planning information graphically in a configuration that is adjustable to the controller's needs.

The TMA will continue to be evaluated and refined using the ATC simulation facility. Ultimately, live traffic testing will be needed to establish the TMA's effectiveness with a high level of confidence.

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Air Traffic Control Simulation Evaluation

H. Erzberger, L. Tobias

As a continuing effort to develop and enhance automation aids for the air traffic controller, a major simulation was conducted in March 1989, to evaluate air traffic control (ATC) automation aids for planning and controlling arrival traffic flow in the Denver Air Route Traffic Control Center (ARTCC) and Terminal Radar Approach Control Facility (TRACON) operations. The simulation included both active and inactive controllers, in two-person teams.

Compared to the previous ATC evaluations conducted in May 1988, the March 1989 simulation included the following enhancements: (1) an expanded descent advisor (DA), (2) a traffic management advisor (TMA) to assist in Denver ARTCC flow control, (3) a Final Approach Spacing Tool (FAST) to assist in TRACON operations, (4) an improved pseudopilot operation, and (5) the use of active Denver ARTCC controllers as test subjects.

The DA is a set of tools used by a controller in a high-altitude arrival sector to assist in intrail spacing operations. The March 1989 simulation added the capability of providing assistance for aircraft over the metering fix at a time specified by the traffic manager. Rather than provide data blocks with time information, the time scheduling and prediction data was presented to the controller on a time line. Using the mouse, the controller could manipulate the data to develop clearance advisories to meet specified times.

The TMA is a real-time scheduler which generates efficient landing sequences and touchdown times for Denver ARTCC arrivals. Its graphical interface and interactive tools are designed to assist the traffic manager in monitoring the automatically generated landing schedules, to override the automatic schedule with manual inputs, and to change scheduling parameters in real time.

FAST is an automation tool for use in the TRACON, but is integrated with the Denver ARTCC planning tools. The final controller is provided advisories for speed adjustment and for initiating turns to achieve the TMA-specified touchdown time. Because of the nature of the final control operations, which precludes any diversion from traffic monitoring, the advisory data appears on the screen when needed and disappears automatically. TRACON controllers indicated considerable enthusiasm for the spacing tools.

A known problem with ATC simulation at Ames Research Center and elsewhere has been the realism of pseudopilot operations. Controllers often solve problems by rapidly issuing clearances to many aircraft. In the simulation environment, these clearances must be entered into the computer system by pseudopilots who can easily get backlogged because of complex data entries and slow system response. The March 1989 simulation used an improved pseudopilot graphics interface that was so effective that, under the moderate traffic conditions simulated, pseudopilots could enter each clearance as rapidly as it was issued, handling up to 12 aircraft in a sector.

Two active Denver ARTCC controllers participated in the evaluation for 1 week and provided many suggestions for using the automation aids more effectively. In a summary report one of the subjects stated, "The system I tested was not an attempt to remove the controller from the loop, but rather a tool box of information with which to make the job of safe, orderly, and expeditious traffic flow more efficient."

The recent tests have proven that the Center automation tools have achieved the level of refinement that is required for live tests and evaluations. As soon as Federal Aviation Administration approvals are received, testing with live traffic data can begin at the Denver ARTCC.

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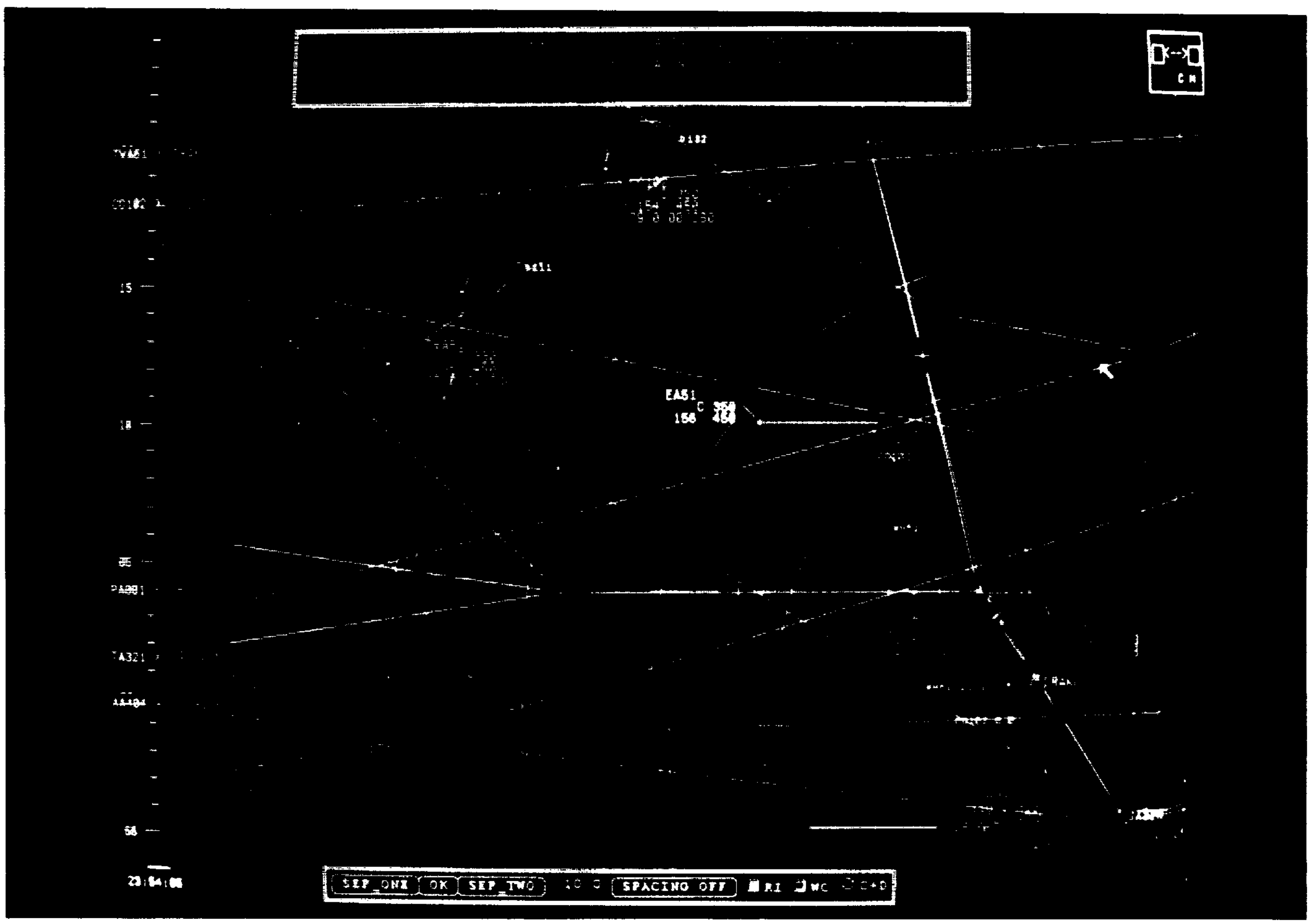
Descent Advisor

H. Erzberger, L. Tobias

The descent advisor (DA) is a set of computer tools designed to assist the controller in controlling descent traffic. These tools build upon the collection of algorithms developed by Ames Research Center for accurately predicting and controlling aircraft trajectories to assist in specific situations encountered in Denver Air Route Traffic Control Center (ARTCC) operations. The DA uses a wide variety of interactive graphic features to provide a clear visual context for understanding the information conveyed.

During 1989, these tools were strengthened substantially. Two major areas of change are the time planning and off-route maneuvering aids.

A typical controller display is shown in the figure. At the left is the primary time planning aid, the time line (a graduated scale whose purpose is to graphically show the future time relationships of aircraft at a designated time control waypoint). The time line includes the following features: (1) aircraft schedule times transmitted by the traffic manager; (2) time ranges for selected aircraft which indicate the earliest to latest time achievable by that aircraft allowing for speed changes in descent, cruise, or both, at the



Display of descent advisor

controller option; and (3) mouse interactive features which allow the controller to select and lock in an assigned time.

The off-route maneuver logic now assists controllers in returning the traffic to standard routes in two modes that can be selected individually for each aircraft—route intercept or waypoint capture. In the figure, CO102 is shown near the top of the screen heading north. In addition, the initial circular turn of the capture profile is shown with a heading advisory to reach the capture waypoint once the turn is completed.

The DA can be used if the aircraft is on or off a standard route, and whether air traffic control (ATC) requires an intrail spacing or a metering mode. It operates in real time. Finally, it was developed and was initially evaluated with current and retired controllers from the Denver ARTCC and elsewhere who have generally shown considerable enthusiasm for its use.

It is planned to use the aids with live traffic data received from the Denver ARTCC. Following these initial tests, and contingent on Federal Aviation Administration approval, it is planned to test these tools on a nonintrusive basis at the Denver ARTCC. In addition, it will be integrated into a terminal area planning system being developed for Frankfurt by the German space agency in an agreement with NASA.

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RASCAL System Definition Simulations

M. Eshow, W. Hindson

A programmable fly-by-wire system will be installed in the UH-60 Rotorcraft Aircraft Systems Concept Airborne Laboratory (RASCAL) helicopter. This system is being developed for an in-flight simulator to conduct high maneuverability and agility tasks in nap-of-the-Earth environments requiring special attention to safety requirements in the fly-by-wire system design. A series of simulations using a UH-60 model were proposed to define the system monitoring and redundancy requirements.

The first of two simulations examining the system implementation questions was done on the vertical motion simulator (VMS). In this simulation, the evaluation pilot controlled the aircraft from an operator's station in the control room while the safety pilot "flew" the aircraft from the VMS cab under motion. Failures were than introduced, and the safety pilot had to take command of the aircraft and attempt to control it.

A new failure rating scale was developed to assist in determining the severity of recovering from failures. Types of failures examined included hardover and slowover inputs in one or more axis during simulated flight at a variety of representative conditions. In addition, bandwidths and authorities less than and greater than the UH-60 were included as variables in the experiment.

Results of these simulations will form the basis for a systems requirement document to guide the design of the aircraft modifications.

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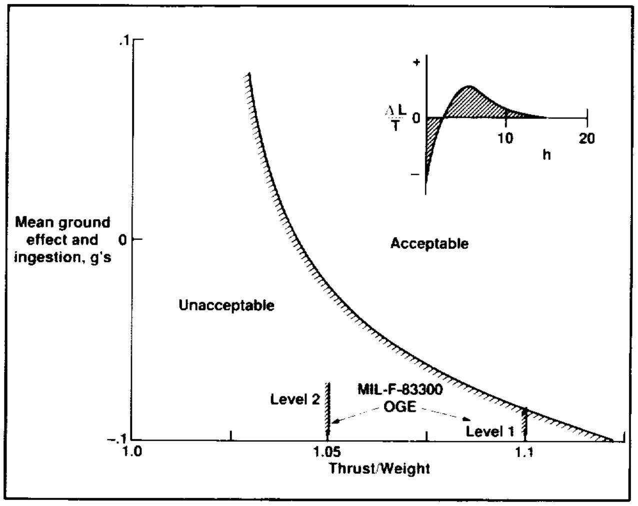
STOVL Flying Qualities Evaluation

J. Franklin, J. Samuels

This project examined the design and performance of short takeoff and vertical landing (STOVL) aircraft during powered-lift operations and the requirements needed for excess thrust, thrust deflection, reaction control, and integrated flight/propulsion controls. A fixed-base simulation of the mixed-flow remote-lift STOVL concept was conducted to evaluate the STOVL aircraft transition envelope, to determine takeoff performance and procedures, to determine control power during powered-lift operations, and to evaluate the integration of the aircraft's flight and propulsion controls.

A powered-lift aerodynamics/propulsion model was developed, based entirely on analytical predictions. Transition and takeoff performance was



Influence of ground effect and hot gas ingestion on thrust margin for vertical landing

defined, including the effects of thrust-vectoring efficiency and excess thrust. Thrust margins were defined for vertical landing as a function of ground effect and hot gas ingestion. Control power use, including reaction control bleed, was established for powered-lift operations. The influence on transition and vertical-landing flying qualities of integrated flight/propulsion control modes was determined.

This simulation provided the first step in defining these interactions and requirements. Furthermore, the potential for achieving Level 1 flying qualities throughout the powered-lift envelope has been established for this STOVL concept.

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CH-47 Flight Research

W. Hindson, M. Eshow, J. Schroeder, D. Watson

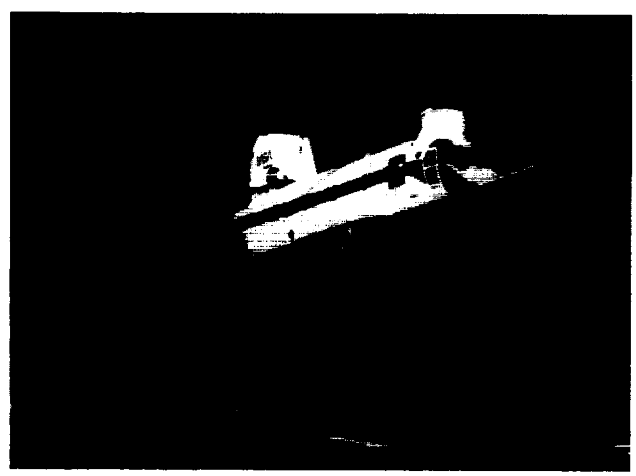
During a 1-year extension to the research life of the CH-47 that was granted by the U.S. Army, several topics requiring flight verification were examined. Accordingly, four experiments and one data gathering exercise were performed.

The experiments and exercise are as follows:

1. Investigate basic display design philosophy by determining the effectiveness of gain versus integrator characteristics for the command element in rotorcraft displays,
2. simulate the AH-64 flight and display characteristics to demonstrate required improvements,
3. simulate the Vertical Systems Research Aircraft (VSRA) Harrier dynamics and displays to prepare for flight of that aircraft in 1990,
4. systematically define for the first time in a rotorcraft context the influence of force-feel dynamic characteristics on handling qualities,
5. obtain actual visual flow-field data from flight for verification of image processing algorithms being developed for automated nap-of-the-Earth flight.

These experiments have been successfully completed. The display design philosophy experiment is an extension of work previously performed at Ames Research Center. It promises significant improvements in the capability of rotorcraft to operate in limited visibility conditions. This hypothesis was demonstrated in the in-flight simulation of the Apache and its display design. The display philosophy experiment and the VSRA display experiment have resulted in fundamental changes to the methodology to be used for the VSRA.

The force-feel dynamics experiment, in a ground-simulation mode, provided results corroborating previous laboratory work. The AH-64 in-flight simulation and the sidestick trim experiment were also successfully completed.



CH-47 variable-stability research helicopter

The force-feel dynamics experiment demonstrates, for the first time, for helicopters the fashion in which the pilot modifies the control strategies to accommodate the dynamics. This type of work is only recently being initiated for fixed-wing aircraft, and has never been systematically performed for rotorcraft. The visual flow data experiment resulted in the only integrated set of actual visual flight data.

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RASCAL In-Flight Simulator

J. Lebacqz

The CH-47 variable-stability helicopter was returned to the U.S. Army in September 1989. A replacement variable-stability helicopter will be developed to permit in-flight validation of controls and guidance concepts. Development of the Rotorcraft Aircraft Systems Concept Airborne Laboratory (RASCAL) vehicle will provide the Nation with its only variable-stability helicopter. This in-flight simulator will provide the capability to validate in flight the integrated controls technology and automated nap-of-the-Earth concepts leading to improved agility and maneuverability.

The UH-60 was selected as the "RASCAL" vehicle after a comprehensive study in which more than a dozen helicopters were analyzed and five were evaluated in flight. The Army delivered the UH-60 advanced digital optical control system vehicle to Ames Research Center in September 1989.

The on-board systems that provide the variable-stability capability must now be developed. This development will proceed through the following phases: concept-definition, design, fabrication, and installation.

During 1989, the efforts have focused on the concept-definition phase. Both a contractual effort and an in-house effort are defining system redundancy requirements, the impact of system failures, the development of failure monitoring schemes, and tradeoffs among maneuverability, safety, system complexity, and cost.

UH-60 advanced digital optical control system Blackhawk demonstrator

The concept-definition phase will be completed and the design phase will begin redefining system redundancy requirements; results will be fabricated and installed in the helicopter. Integrated controls flight experiments will begin in FY 1994 or FY 1995.

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Civil Tilt-Rotor Airworthiness Criteria

J. Lebacqz, W. Decker

Provisional certification of a civil version of the MV-22 tilt rotor may be accomplished so that the ramifications of introducing tilt-rotor aircraft into the National Airspace System can be assessed. Consequently, there has been renewed interest in the definition of suitable airworthiness criteria for this class of aircraft, including a new Federal Aviation Administration (FAA) set of interim criteria published in July 1988. These criteria, however, are based largely on attempts to blend criteria for conventional aircraft and rotorcraft, and are based on data for configurations substantially different from tilt rotors. Accordingly, experiments on the Ames Research Center

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MV-22 tilt-rotor aircraft

Vertical Motion Simulator (VMS) have been initiated to address these operational and airworthiness issues for tilt-rotor class aircraft.

Initial experiments were conducted in 1983, and were based on 13,000-pound XV-15 aircraft to attempt some flight correlation. These experiments examined the manner in which conversion from air-borne to thrust-borne flight is effected, the coupling between conversion and aircraft pitch and heave control, and the allowable range of airspeeds at given thrust inclination angles. This simulation model was revived in October 1988, and a ground-based simulation was conducted of similar variations for a new set of FAA and Civil Aviation Authority experts. This simulation confirmed the influences found earlier, and initiated an examination of one-engine-inoperative situations, which is a key driver for operational acceptance of the tilt rotor.

Airworthiness and operational issues are tightly coupled for tilt-rotor class vehicles, and these studies define technological advances that are required to meet the safety objectives of civil operations. For example, the requirement for one-engine-out operations can be a major design driver for the next generation of tilt rotor.

The concepts that have been examined for the XV-15 class of tilt rotor are being carried over to a new model of a 40,000-pound tilt rotor very similar to the V-22 (at least in performance). A VMS experiment with this model began early in FY 1990.

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VSRA Thrust Model Calibration for Aerodynamic Modeling

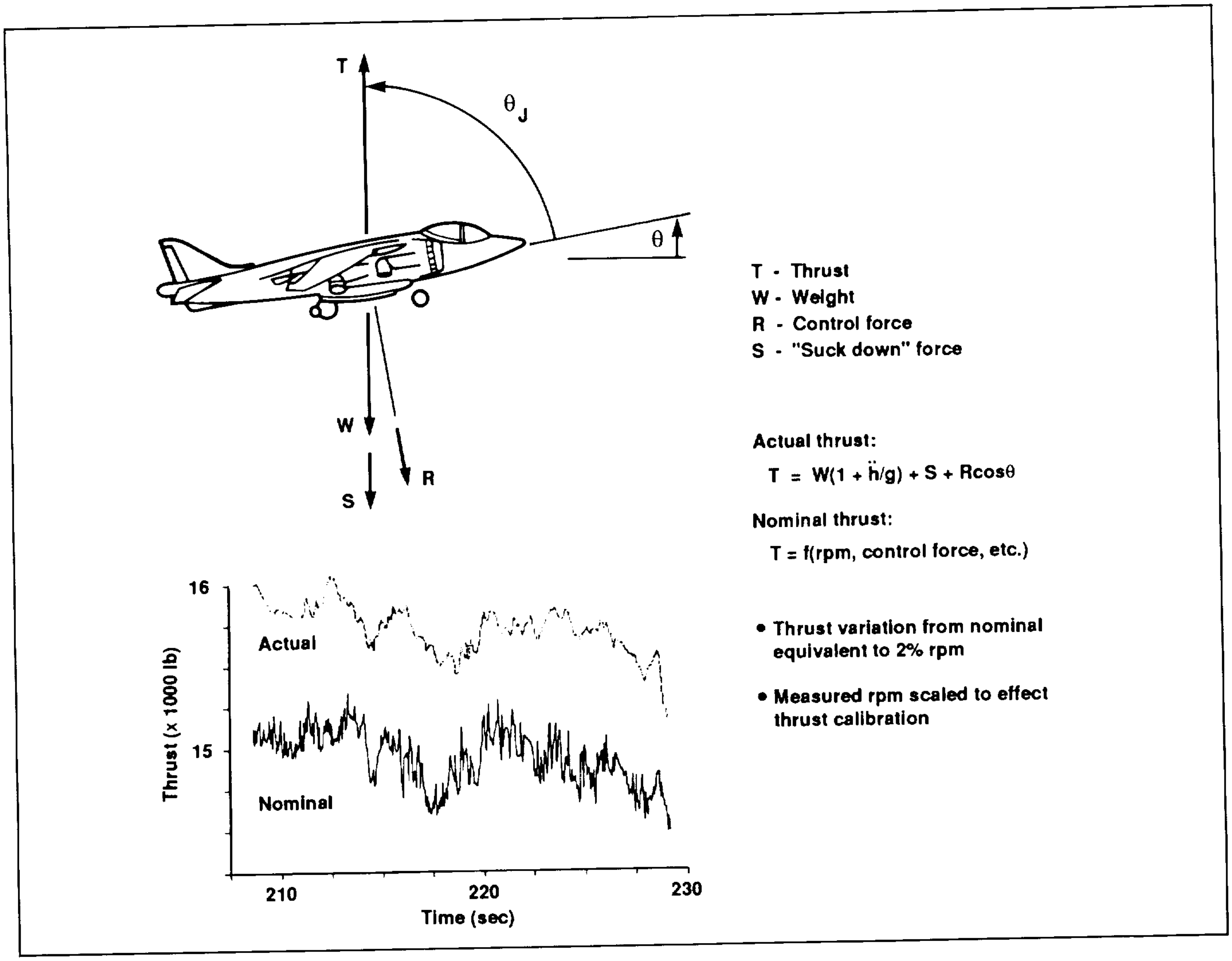
D. McNally, R. Bach

The objective of this program is to define and identify a full-envelope aerodynamic model of the vertical and short takeoff and landing (V/STOL) Research Aircraft (VSRA) from a flight-test data base. The model must represent VSRA body forces and moments over a flight envelope that includes hover, transition to forward flight and back to hover, as well as short takeoff and landing (STOL) operation and normal cruise. The new aerodynamic model is needed to update a VSRA simulation that supports ongoing research in advanced control, display and guidance concepts for short takeoff vertical landing (STOVL) aircraft.

Aerodynamic forces and moments acting on the VSRA in flight are determined as the difference between total forces and moments and propulsion system forces and moments. A nominal thrust model is used to compute thrust from measurements of key engine variables such as rpm, Mach number, thrust deflection angle, and control positions. Since actual engine thrust may differ from nominal engine thrust by as much as 3%, the nominal thrust model must be calibrated to match flight-test estimates of engine thrust.

Analysis of hovering flight data has been used for thrust model calibration. The engine thrust in hover must balance the inertial forces, the control forces, and the aerodynamic suck-down force. The inertial and control forces may be computed from flight data. Suck-down is an aerodynamic force due to entrainment of ambient air toward the main engine jet in hover, and is equal to about 2% of thrust. Calculations of actual thrust and nominal thrust were compared for selected hover segments. The comparison is shown in the figure.

The difference was converted to an equivalent scale factor applied to the measured engine rpm. This technique was used for two reasons: (1) since measured engine rpm has the largest influence on modeled thrust, thrust model output may be easily scaled by scaling the engine rpm, and (2) a measurement error in engine rpm would contribute significantly to a difference between actual and nominal



VSRA thrust model calibration from hover measurements

thrust. A scale factor applied to engine rpm will correct the nominal thrust model in either case. Results indicate a consistent thrust correction equivalent to 2% engine rpm at the hover condition.

Because engine performance can vary significantly from nominal, a thrust model calibration must be performed when the model is to be used for critical force and moment computations. It should be emphasized that the aerodynamic model identified from flight-test data can only be as good as the propulsion model used to isolate aerodynamic forces and moments. Aerodynamic forces and moments are being isolated from the data base using the calibrated thrust model. Aerodynamic modeling of the VSRA using parameter identification techniques is ongoing.

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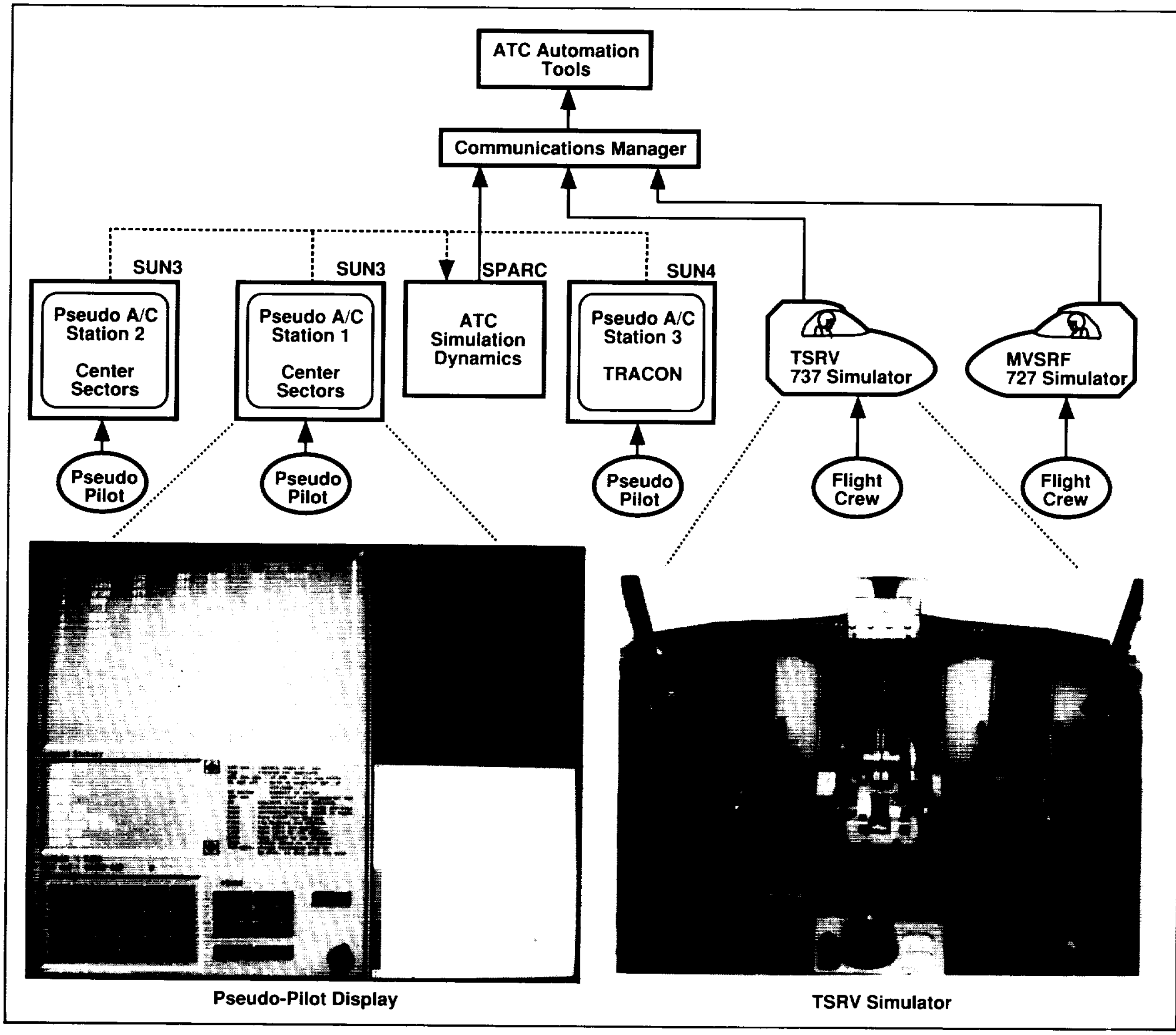
Air Traffic Control Automation Aids Evaluation Environment

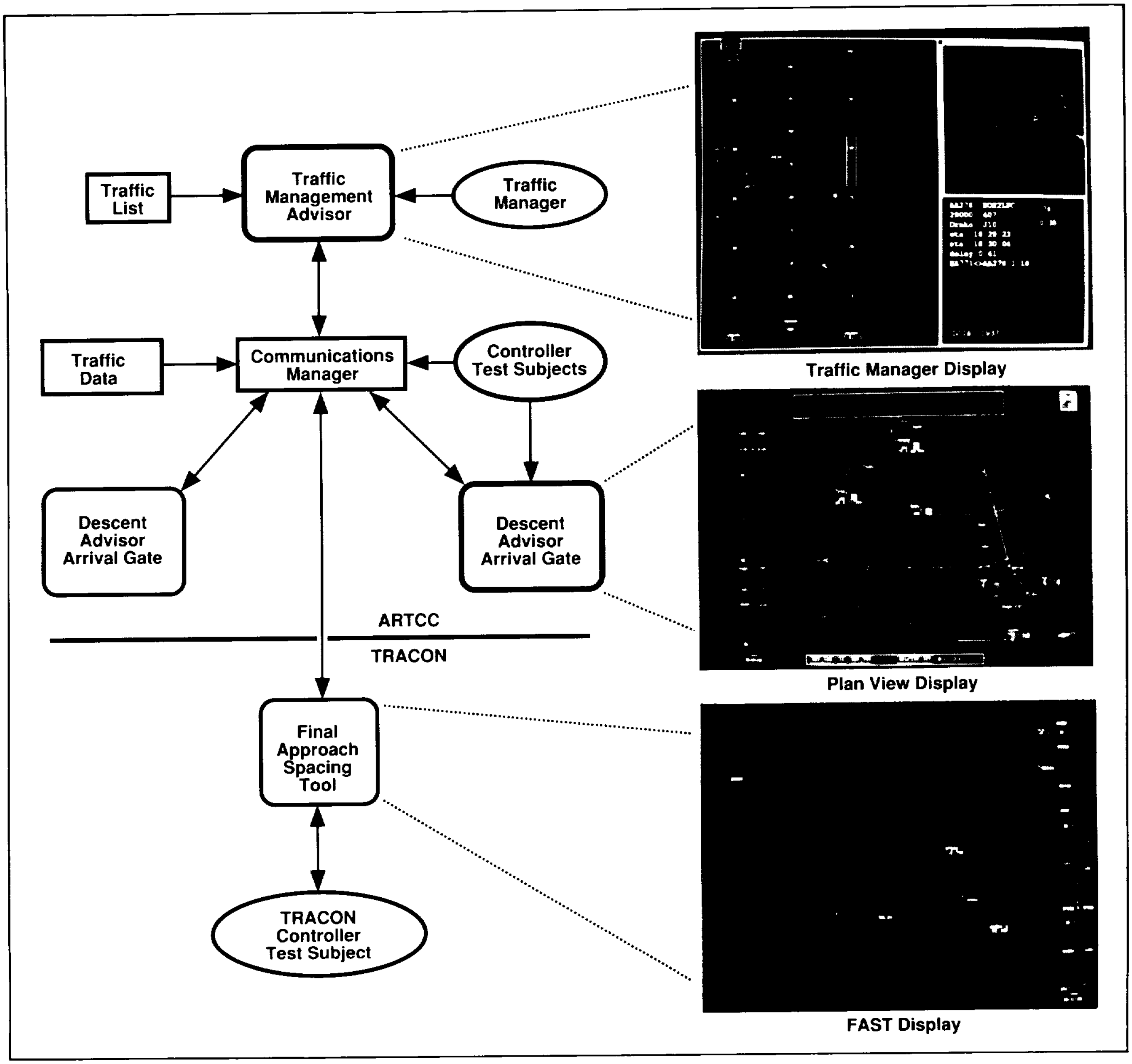
J. Saito

To support the Air Traffic Control (ATC) Automation Research Program, it has been necessary to develop an ATC research simulation facility using interactive graphics and advanced ultra high resolution color display monitors within a workstation environment. The facility includes a network of interactive color graphic workstations and Artificial Intelligence (AI) computers with data links to real-time piloted simulators at Ames Research Center, Langley Research Center, and the Federal Aviation Administration (FAA) Denver Air Route Traffic Control Center (ARTCC) for access to live traffic data.

The ATC Simulation Laboratory construction was completed during the first quarter of 1989 and houses nine SUN workstations networked together with two AI computers, a sector suite which uses the display monitor developed by Sony for the FAA's Advanced Automation System and three data links. The first figure shows the functional elements and actual displays of the Air Traffic Simulation half of the laboratory. The second figure shows the functional elements and displays of the ATC Automation



Air traffic simulation



Air traffic control automation tools

Tools for the other half of the laboratory. The Denver air traffic data (slow update rate) has been successfully integrated with the simulation facility and displayed on the controller displays. A National Airspace System (NAS) Change Proposal (NCP) software patch has been developed, coded, and tested for transmitting Denver ARTCC tracking and metering data to NASA Ames Research Center at the standard ATC radar update rate of 12 seconds.

The ATC Simulation Laboratory is a unique national facility that can be used to examine a wide range of ATC issues including automation aids development, Denver ARTCC Terminal Radar Approach Control Facility (TRACON) coordination, and integration of four-dimensional-equipped aircraft into system operation. Furthermore, the facility has access to real-time radar, weather data, and multiple piloted simulators which can be used to understand current operational problems and to develop controller aids for the advanced system.

The automation aids being developed will demonstrate the effectiveness of ground-based, four-dimensional guidance and planning algorithms when they are integrated with state-of-the-art interactive graphics systems.

The NCP for faster update rate has been written and submitted for approval to the FAA. Preliminary tests indicate that the FAA operations at Denver ARTCC can be sustained without degradation while transmitting air traffic data to Ames at the faster data rate.

Plans are to implement the NCP at Denver and to continue the automation aids development using the ATC Simulation Laboratory connected to piloted simulators. To fully validate the aids, this should be followed by installation and testing at the Denver ARTCC.

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Helicopter Maneuver Envelope Enhancement

J. Schroeder, M. Whalley

Rotorcraft pilots are unable to use the full flight envelope of their aircraft. Actual performance limits on today's operational helicopters are unknown to the users, and little or no cuing is available to the pilot to monitor the approach of the limits; consequently, the flight demonstration of new helicopters typically is conducted to the specification only, and the full available envelope is not used. It is desirable then to define the limits and to develop and demonstrate methods to fully use the helicopter's performance capabilities, which is sometimes called carefree maneuvering.

A contracted study was conducted using the UH-60 Blackhawk as the example helicopter. In the study, key structural and aerodynamic maneuver limiting phenomena were identified, and the contractor's fixed-base simulation extended to an in-house simulation conducted on the Vertical Motion Simulator at Ames Research Center.

The study determined that three principal limiting factors in the helicopter's flight envelope are main rotor control loads, tail rotor moment, and main rotor moment. Because the most important of these, control loads, was not available in the simulation model, measures which approximate the same envelope were developed.

For the simulations, a variety of cues for the pilot were investigated (including lights, tones, additional symbols on a head-up display, or stick shaking), and representative tasks to push the flight envelope usage were examined. This manned simulation showed, through both pilot ratings and comments, that the cuings tested did not allow a pilot to use more of the available envelope without an increase in workload; however, the pilots were able to develop strategies, after much practice, to minimize limit exceedances for the canned tasks considered.

It is clear from the results of this study that these limits are dynamic in nature, and avoiding their exceedance in a "carefree maneuvering" sense requires more than displaying some of the information to the pilot. Accordingly, automated limit exceedance and envelope enhancement must be considered as the next step.

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Effect of Data Resolution on Aircraft State and Wind Reconstruction

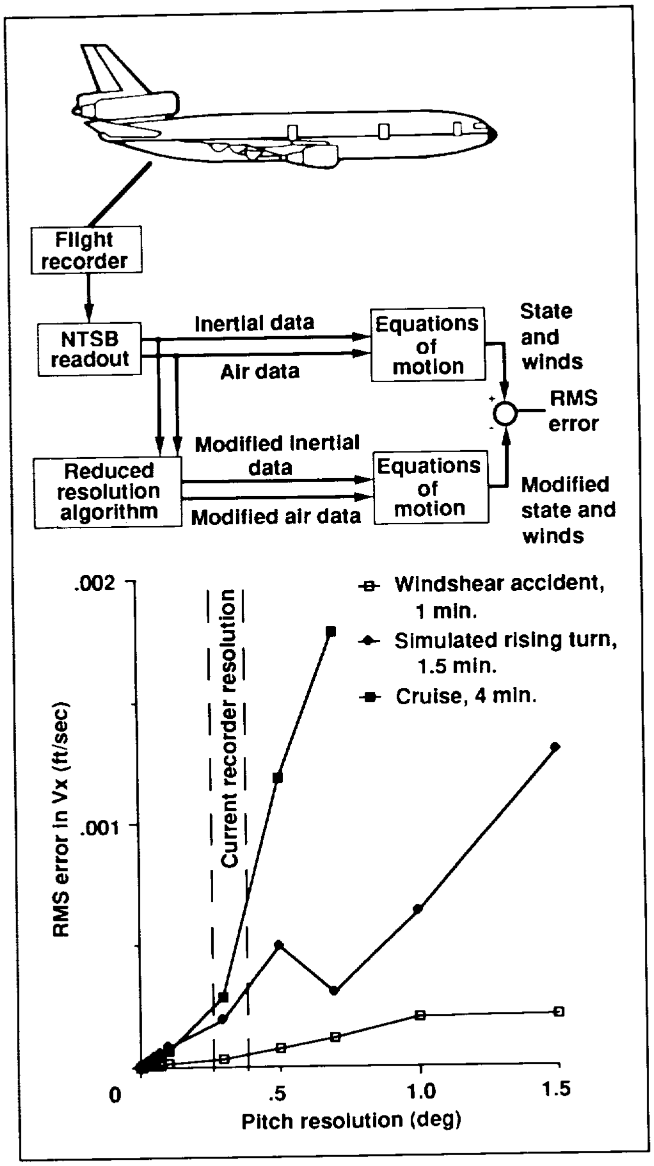
T. Schultz

The Federal Aviation Administration and the National Transportation Safety Board (NTSB) are recommending the installation of flight data recorders in more aircraft including commuter and general aviation categories. The availability of high-technology, solid-state flight data recording equipment is one basis for their recommendation. The solid-state recorders have advantages over their electromechanical counterparts, such as reduced weight and space requirements; however, available memory storage is limited. Various data compression schemes are being used in conjunction with lower data resolution to offset the memory limitation. The objective of this research is to determine which flight recorder parameters can possess lower resolution without greatly affecting the accuracy of the trajectory and wind reconstruction.

The numerical study is based on three data sets, two from commercial airline digital flight recorders and one from an aircraft simulation. The three data sets were chosen because they represent different flight conditions for a commercial aircraft. The first set is made up of 1 minute of data from a recent windshear accident, the second set consists of 4 minutes of commercial airliner cruise data, and the third set includes 1.5 minutes of data from a simulated aircraft's rising turn.

The three data sets and duplicates of the data sets with degraded resolution were used in this study. Both actual and degraded sets are used independently to calculate the airplane's state history and to estimate the encountered wind history. The error between the airplane's state history obtained from the actual data set and the state history calculated from the degraded data set serves as a measure of degraded data resolution. The sensitivity of the trajectory reconstruction and wind estimates to raw data resolution are used for parameter resolution recommendations.

The results, illustrated in the figure, show a tradeoff between reconstruction accuracy and data resolution. Fairly accurate results (reconstructed trajectories and winds) can be obtained with compressed records containing word lengths somewhat less than those now being used in digital flight data recorders on board current airlines. In conjunction with the NTSB, this information is being distributed to United States and European agencies that are considering the standards for the next class of flight data recorders.



Effect of data resolution on aircraft state and wind reconstruction

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Verification Data for Passive Ranging

P. Smith, B. Sridhar

The objective of this project is to acquire video image data and ground truth information for developing and verifying computer vision-based passive ranging algorithms to aid the pilot during rotorcraft nap-of-the-Earth (NOE) flight.

Research in image-based obstacle detection has led to the development of several algorithms which perform well based upon results obtained using laboratory data. The laboratory data are, however, necessarily limited in camera motion and noise encountered as compared with true rotorcraft flight. In the absence of any available real-world data which integrates the essential data components, the NOE Image and Truth (NOE-IT) Data Acquisition Test Flight Project has been undertaken to acquire such a data set.

The integrated data set consists of three major components: (1) video image data, (2) motion states of the video camera, and (3) true positional data of obstacles appearing in the video images. The first and second components of the data set are used to estimate range to obstacles using the above-mentioned algorithms, while the third component is used to check these results with the ground truth.

As shown in the figure, NOE-IT uses an instrumented Boeing CH-47B Chinook (NASA 737) as a testbed, on which video acquisition and recording equipment is installed, to provide the first data component. Rotorcraft motion is obtained from the inertial navigation unit and other onboard instruments whose output is telemetered to a ground station for storage to form the second component. Laser tracking provides ground truth measurement of the rotorcraft's location, while both laser tracking and surveying provide the obstacle locations to complete the data set.

The video equipment has been installed on the CH-47B Chinook, along with the pre-existing motion instrumentation and telemetry system. Flight profiles

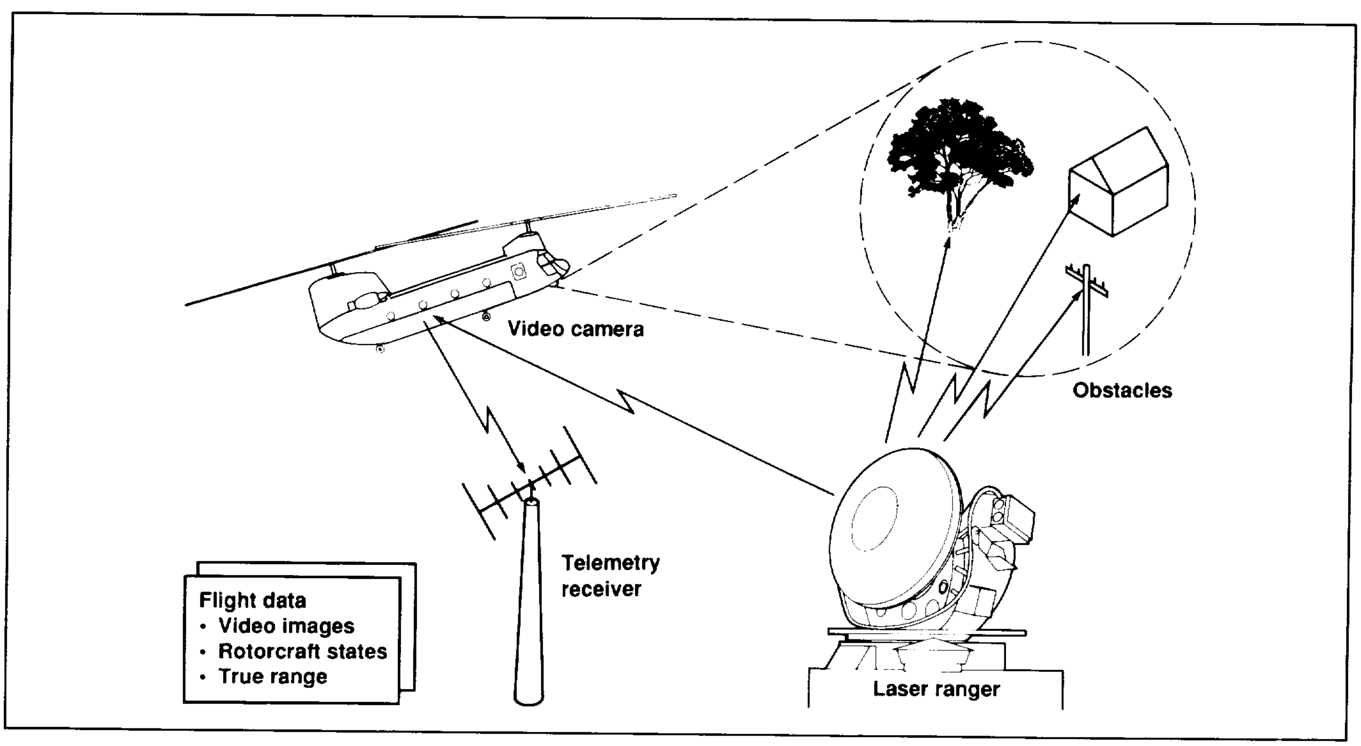

Image data for validation of computer vision passive ranging algorithms have been defined and pertinent obstacles (including foliage, buildings, and transmission towers) have been selected. Preliminary flights to verify proper system performance are near completion and a full project readiness review is scheduled.

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Autonomous Lander Hazard Detection

B. Sridhar, V. Cheng

The objective of this program is to examine the use of vision-based methods to detect surface hazards in the landing phase of an autonomous lander. The program will use the laboratory facilities and build on similar research being conducted to detect hazards during helicopter low-altitude flight and landing (see the figure accompanying the following article).

The autonomous lander hazard-detection problem is viewed as a problem of determining shape from motion of the sensors augmented by stereoscopic imagery and other vision processing techniques as deemed appropriate. We have examined two approaches, "field-based" and "feature-based," for recovering range from motion.

Field-based algorithms perform range estimation for every point in the image by studying the intensity variation analytically over time. They have the potential of providing a complete map of the hazards in the field of view. However, the computational experience with natural images using this approach is limited.

Currently, we are using two different algorithms: (1) a feedback solution to the image irradiance equation, and (2) velocity filtering to get a better understanding of the computational issues. Feature-based algorithms identify and relate features in successive frames through correlation. We have developed a Kalman filter-based recursive estimation technique to get range information using a sequence of images.

Both the field-based and feature-based approaches will require augmentation by other methods such as shape from shadows, shape from shading, or texture analysis. An amendment to an existing contract with Honeywell is being negotiated to investigate augmentation of the basic shape from motion algorithms with these other methods to provide a reliable hazard-detection algorithm for the landing phase.

During 1990, the integration of these methods will begin. The effectiveness of the algorithms will also be examined using images from simulated Mars scenarios generated by the Jet Propulsion Laboratory in Pasadena, California.

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Obstacle Detection

B. Sridhar, R. Suorsa

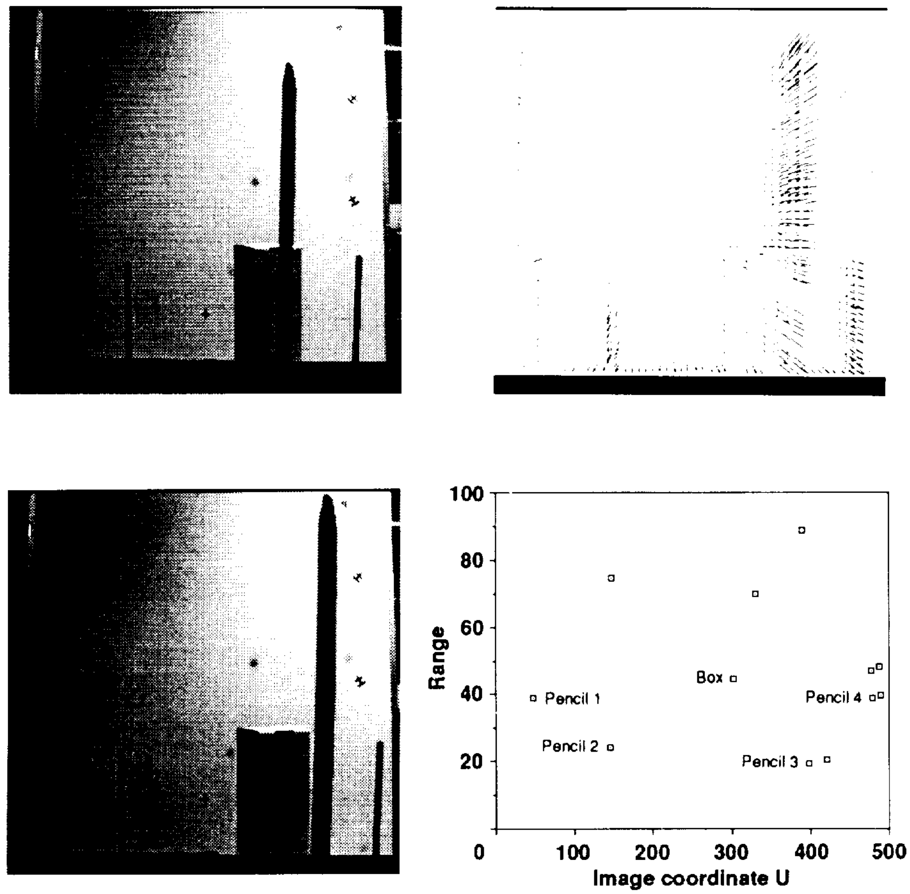
The objective of this program is to develop obstacle-detection algorithms for the autonomous guidance of vehicles and, in particular, for rotorcraft nap-of-the-Earth flights. The reliable detection of obstacles is a key element in advancing the automation of rotorcraft.

Research in this area has focused on (1) establishing a vision-based architecture identifying research components; (2) developing and assessing alternative vision-based methods; (3) developing a laboratory which can generate image data under controlled conditions and is capable of processing image data from several different sources such as magnetic tape, camera, video tape, and other sources; and (4) validating the vision-based algorithms using both laboratory and flight data.

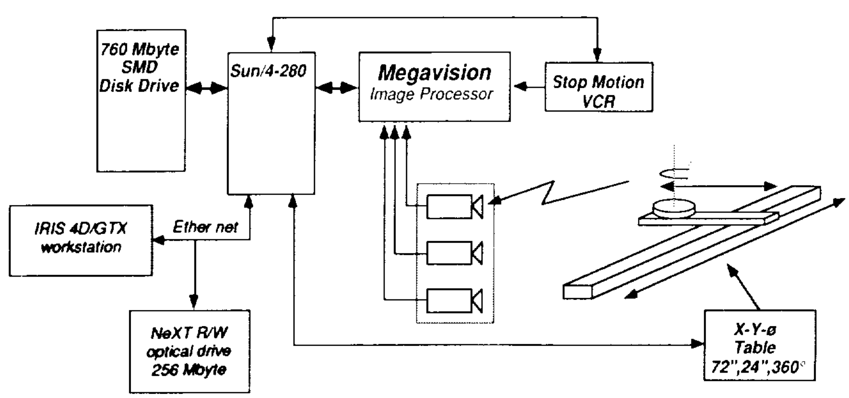
The in-house work is augmented by a contract with Honeywell Systems Research Center and by two Small Business Innovative Research (SBIR) contracts awarded to Space Computer Corporation and Advanced Decision Systems. Work in this area is also supported by grants to Georgia Institute of Technology, University of Michigan, and Stanford University.

A significant accomplishment during 1989, illustrated in the figure, was the development of a recursive algorithm to estimate the range of objects in the

VALIDATION OF FEATURE BASED METHODS FOR CONTROLLED DATA SET



LABORATORY CONFIGURATION



Vision-based obstacle detection

field of view and the validation of this algorithm using a sequence of images collected in the laboratory with the camera moving linearly. This algorithm will be further validated with images involving rotary motions of the camera and with images collected in flight using the NASA CH-47 helicopter. The vision laboratory is being updated with the addition of a SUN/4-280 as the host for Megavision 1024 Image

Processor and a computer-controlled 3-degrees-of-freedom camera drive.

The obstacle information provided by computer vision algorithms based solely on motion analysis is not complete and needs to be augmented by other techniques such as stereo and scene analysis. The plan for next year includes integration of stereo, motion, and scene analysis to provide more complete obstacle information and the validation of these algorithms using both laboratory and flight data. The obstacle-detection techniques resulting from this effort will provide an initial range map for use by rotorcraft obstacle-avoidance algorithms and can be considered as a candidate for detecting hazards during the terminal descent phase of a Mars landing.

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Helicopter Computer-Aided Low-Altitude Flight Path Guidance

H. Swenson

The mid-field planning problem can be characterized by real-time precise path definition based on knowledge of the terrain, threats, and mission objectives. Terrain following/terrain avoidance (TF/TA) research for high-performance aircraft is an example of the mid-field path planning problem. As part of the automated nap-of-the-Earth (NOE) program, a research effort has been conducted to develop a computer-aided low-altitude flight path guidance capability for helicopters. This effort is a first step in examining the control/display requirements for the pilot/system interface of an automated NOE guidance system.

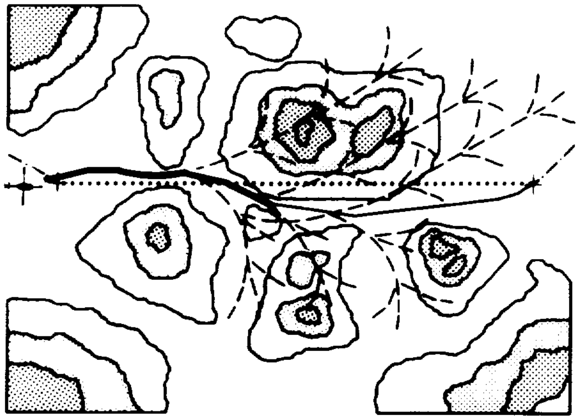
The figure illustrates the three major elements of the research. A guidance algorithm, known as Dynapath, is the center of the computer-aided low-altitude guidance concept. The algorithm employs dynamic programming for generating an optimal trajectory based upon a priori knowledge of terrain, waypoints, threats, and aircraft performance parameters. It was initially developed with the aid of an off-line computer simulation to reflect the dynamics and constraints of helicopter operations. The use of piloted simulations has led to significant refinements along with the development of a pilot interface and head-up display (HUD) guidance symbology for maximum pilot understanding with minimum pilot workload.

Three successful piloted simulation investigations have been conducted. The first concentrated on the integration of all the essential elements required for piloted evaluation of the guidance concepts. During the second piloted simulation, the update logic necessitated by the asynchronous nature of the algorithm was developed along with the display symbology and guidance laws. Baseline pilot evaluations were also conducted.

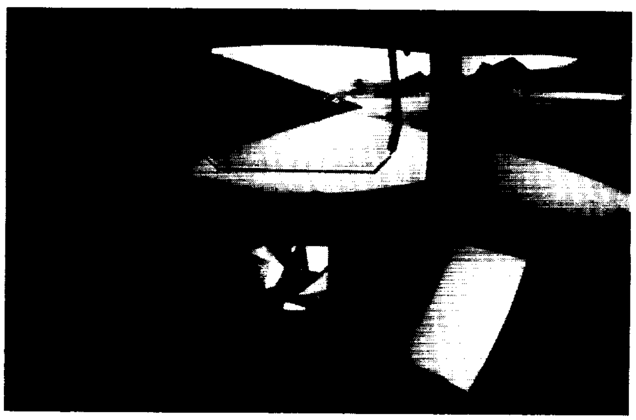
The third piloted simulation, conducted in fall 1988 on the Ames Research Center Vertical Motion Simulator, focused on three primary objectives: (1) extending the algorithm to accept variations in speed; (2) determining performance limits on the guidance commands through the use of the motion-based simulator; and (3) obtaining an operational pilot evaluation of the system throughout its performance limits. Ten pilots representing NASA, the U.S. Army, and the U.S. Air Force flew 302 simulation runs, with an average run covering 15 miles, over extremely varying terrain. The pilots flew at varying speeds and altitudes ranging from 40 to 100 knots and 40 to 100 feet, respectively. Runs were also included with decreased visibility (1/4 mile) and moderate turbulence. The pilots followed the guidance with very low path-tracking errors (3-15 feet standard deviation) and rated the system as easy to fly and predictable in nature.

Development of the flight-guidance concept supports the fully autonomous NOE flight program. The derived path can be used as a nominal route with obstacle-detection sensors and an obstacle-avoidance algorithm providing fine control at lower altitudes. Developing the pilot displays for use with the system will provide an initial understanding of the displays required for NOE flight. In addition to being critical to eventually achieving automated NOE flight, the concept has been identified as potentially serving the needs of Special Operations Forces as a stand-alone capability.

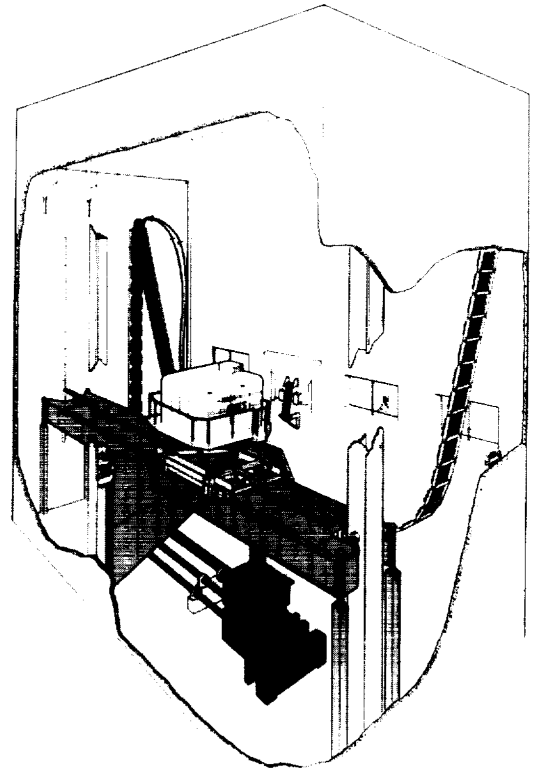
The current computer-aided low-altitude guidance concept has been tested and has matured as a single system development. Integration of the concept into flight testing is the logical next step.



Real-time optimal trajectory computation



Flight path centered display



Operational pilot acceptability simulation VMS simulator

Helicopter terrain following/terrain avoidance flight path guidance

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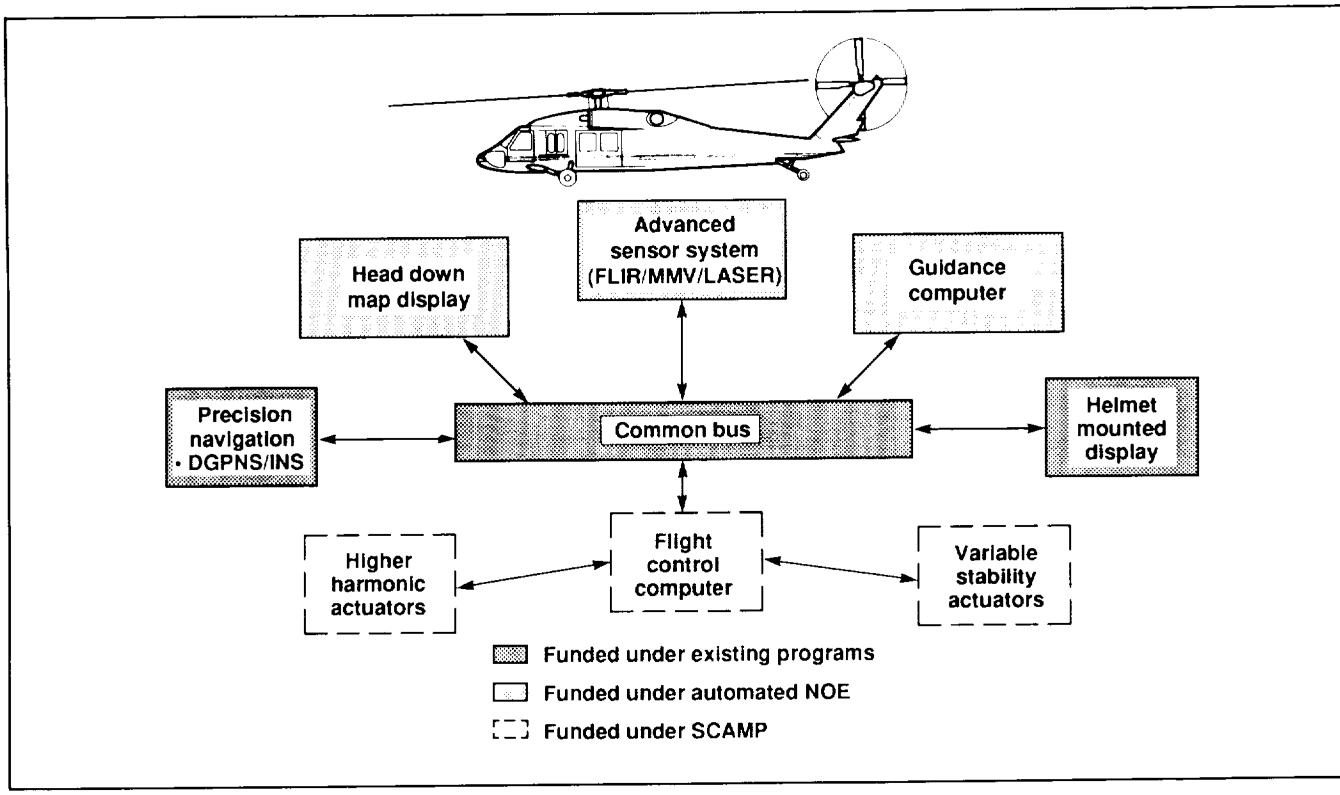
Helicopter Flight Research Vehicle

H. Swenson

A key to the successful development of the automated nap-of-the-Earth (ANOE) flight program is testing the various elements of the program in actual flight. This truth testing will give timely results to those elements which require engineering tradeoff decisions for overall program success.

The Rotorcraft Aircrew Systems Concepts Airborne Laboratory (RASCAL) shown in the figure, can provide the testbed capability. The RASCAL will require advanced pilot displays; a precision navigation capability; high-speed research computers; and as the ANOE program progresses, advanced sensor systems. The flight control capability will be provided under the Superaugmented Controls for Agile Maneuvering Performance (SCAMP) program.

The first planned flight experiment will be an operational evaluation of the computer-aided low-altitude guidance which has been successfully tested in simulation. This is intended as the first step in developing an automated NOE flight research capability. A Memorandum of Agreement is being drafted with the U.S. Army Avionics Research and



Helicopter flight research vehicle

Development Activity for the demonstration of this concept as a potential stand-alone capability in the support of future Special Operation Force requirements.

The experiment will require a precision navigation capability (currently being developed for the differential global positioning system program), an advanced high-speed computer for the implementation of the computer-aiding concept, and a helmet-mounted or head-up-display for presenting the guidance commands to the pilots. All these elements will be integrated through a common aircraft avionics bus.

Plans for the system design are being initiated. The intent is to develop a system to meet the needs of the first flight experiment and which can be upgraded with new sensors, computer, and controls as the ANOE and SCAMP programs progress.

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Rotorcraft Systems Identification

M. Tischler, J. Fletcher

The objective of this research was to develop system identification tools that are appropriate for the rotorcraft application, which implies a need to deal with high order systems that are highly coupled. These tools are required to validate mathematical models from flight data, to permit the design of advanced flight control systems, and to verify compliance with military specifications. The approach has been to develop frequency domain methodologies with user-friendly software, and then to participate with international organizations to compare and improve the methods by applying them to a wide variety of U.S. Army and international rotorcraft.

A major effort was completed as part of the Advisory Group for Aerospace Research and Development Working Group #18 on Parameter Identification. A very robust model of the BO-105 helicopter was developed from flight data using the frequency-domain-based techniques.

In general, it has been found that these techniques provide a more useful approach to the rotorcraft parameter identification because of the emphasis on high-frequency dynamic modeling and model reduction that is required. In addition to these results, documentation of the XV-15 dynamics was prepared, demonstration of the procedure as a specification compliance requirement was completed for the 214-ST helicopter, and an overall system identification software facility was shown in a prototype form.

The frequency-domain approaches, when compared one-to-one with other techniques, have shown distinct advantages for many aspects of the parameter identification problem, and are now recognized as the preferred approach for addressing most rotorcraft problems.

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Flight Operations and Research

Airborne Information Management System

G. Bever

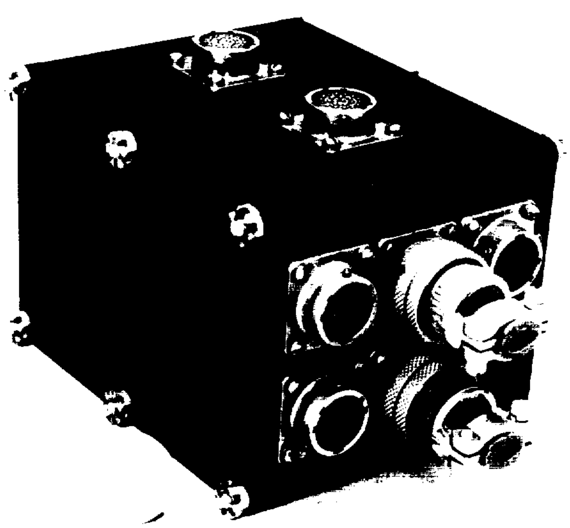
Flight research requirements are pushing the limits of data management, particularly in real time. Rather than merely "pushing the edge of the envelope" to send more data faster and doing a "fast shuffle" at the receiving end, the Airborne Information Management System (AIMS) project is aimed at managing the data at the transmission end, i.e., on the aircraft. By applying techniques of data compression, digital filtering, and real-time analysis, it is expected that increases in data requirements can be handled more appropriately. In addition, with its physical design goals (small, modular, distributable system capable of functioning in harsh environments), this Transputer-based system should see a wide range of applications from model aircraft to hypersonic vehicles.

AIMS is seen as being a multiprocessing system whose processors can be colocated on the aircraft, or distributed throughout the aircraft. It will be small and completely modular, so that the system's physical size can reflect the processing and input/output requirements. A typical module stack will be approximately the size of two fists (see the first figure).

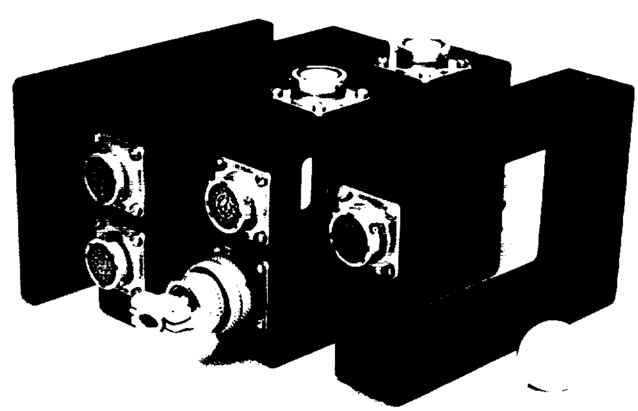
Even if a "logical" block requires more modules than will fit into a given area, the architecture will allow the logical set to be divided into smaller physical blocks for placement in convenient areas (see the second figure). It is desirable to keep analog sensor leads as short as possible to reduce the noise pickup. For this reason (as well as for minimizing the quantity of wires bundled throughout the aircraft), it may be desirable to place part of the system in each wing, and another in the tail area, or in the avionics bay, or mount part of the system in the engine compartment.

Connectors will be used that make it easy for instrumentation crews to perform tasks such as grasping, inserting/removing pins, and connecting/disconnecting. (This is the practical limitation in how small the modules can be. This should minimize the need to install connector blocks onboard for the sole purpose of converting connections to something crews can easily work with.) Refer again to the figures.

Simultaneous sampling (or quasi-simultaneous, using high-speed analog to digital converters) will be used to minimize time skewing of sampled data. Enough onboard processing power will be available (through multiprocessor expansion, if necessary) to perform high-speed computations, such as digital fil-



AIMS Stack



AIMS module housings—disassembled

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tering, data compression, and display formatting.

AIMS is much more powerful than existing data acquisition systems. Improved capabilities include remotely programmable signal conditioning, onboard digital data storage, and high-speed 32-bit parallel processing which allows data compression, time for frequency domain conversion, and digital filtering. Harsh environment operation (such as engine bays or hypersonic vehicles) is mechanized by the use of liquid cooling, which allows efficient heat transfer through the system and, if necessary, through external heat exchanging mechanisms.

AIMS is expected to become the standard instrumentation system at Ames-Dryden Flight Research Facility. Because its design is inherently fault-tolerant, other disciplines—such as flight controls and avionics—are interested in its potential use in those areas.

Elements of AIMS are currently supporting the F-104 Windshear program, and are planned for the Convair 990 Shuttle landing-gear program, as well as the F-18 High-Angle-of-Attack vehicle.

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A Design Procedure for the Handling Qualities Optimization of the X-29A Aircraft

J. Bosworth, T. Cox

A design process for improving the pitch axis handling qualities of a flight vehicle was developed for the X-29A. The process is believed to be applicable to all fighter-class airplanes that exhibit a linear response to small amplitude inputs. The method works with the existing flight-control system architecture to fine-tune the handling qualities of the vehicle. Since the procedure is a fine-tuning process, results from flight tests are required to validate or update the mathematical models used in the process.

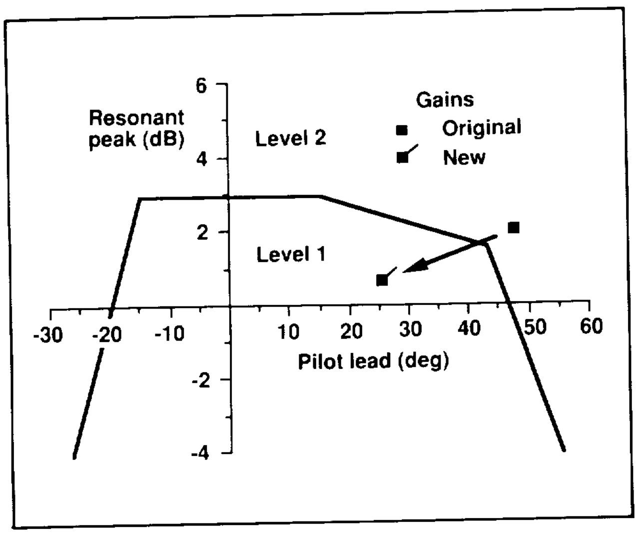
Control law development for new aircraft follows a natural evolutionary process. The initial mathematical models have a relatively high degree of uncertainty, which requires that the control law design stresses stability and robustness to account for this uncertainty. Consequently, other desired objectives such as performance and handling qualities may be initially compromised to obtain the required robustness. This was true for the X-29A aircraft. With a highly unstable aircraft, it takes very little control surface deflection to initiate a change in the pitch attitude of the aircraft. The majority of the control power is required to arrest the motion when the desired pitch attitude is achieved. With the modeling uncertainties, the initial control system designers reduced the allowed pitch acceleration to ensure that the resulting motion could be controlled and arrested when desired.

After a vehicle is brought to flight test, flight data can be used to validate or update the mathematical models to match the flight-test vehicle. The more exact mathematical model allows the constraint on robustness to be relaxed and the control laws can be adjusted to provide improved handling and performance. However, at that point in the flight control system development it is usually not feasible to make major changes which would be costly and may reintroduce high levels of uncertainty. Instead, it is desirable to improve the handling and performance of the airplane by making relatively minor changes in the existing control law structure.

The envelope expansion flight-test phase of the X-29A was completed in August 1987. During this period, dynamic stability and handling qualities characteristics were investigated throughout the flight envelope. A variety of tasks were flown to provide a qualitative look at the initial handling qualities of the vehicle. Even with the emphasis on robustness in the design process, the handling qualities of the vehicle were rated as borderline level 2/level 1 as defined by current military specification standards. However, pilot comments indicated sluggishness in the pitch axis. The question remained as to whether a vehicle with a 35% negative static margin could be improved to fly with the initial accelerations and precise control required of a level 1 fighter-type aircraft.

A design process was developed to improve the handling qualities of the X-29A aircraft. The challenge was to increase the maneuverability of the vehicle, while maintaining adequate levels of dynamic stability. The design algorithm used the existing control system architecture to provide improved handling qualities and acceptable stability with a minimum of cost in both implementation and flight-control system software verification and validation. The Neal-Smith handling qualities criterion was used as a quantitative measure of the handling qualities. Efficient algebraic frequency domain manipulations were used to allow the assessment of many combinations of control system gain changes in an optimization process.

Flight data that were generated by the modified gains show that the X-29A exhibits level 1 handling qualities according to the Neal-Smith criterion (see figure). Pilot comments also indicate that the improved design provides pitch responses that are comparable to the best of current fighter-class airplanes.



Neal-Smith analysis comparing the modified gains with the original gains

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Remotely Augmented Vehicle Expert System

D. Cohen

The remotely augmented vehicle expert system (RAVES) is designed for enhanced real-time monitoring of flights in the remotely augmented vehicle (RAV) laboratory. The current displays use no graphics, mouse, or color capabilities; they are simple text displays. RAVES uses color graphics and mouse capabilities for quicker detection of in-flight problems and ease of use.

RAVES is based upon software from the Real-Time Display System used by Johnson Space Center in support of the space shuttle.The benefits of using their software is twofold. First, it reduces development costs by using existing software. And second, it allows both groups to share new developments to the software.

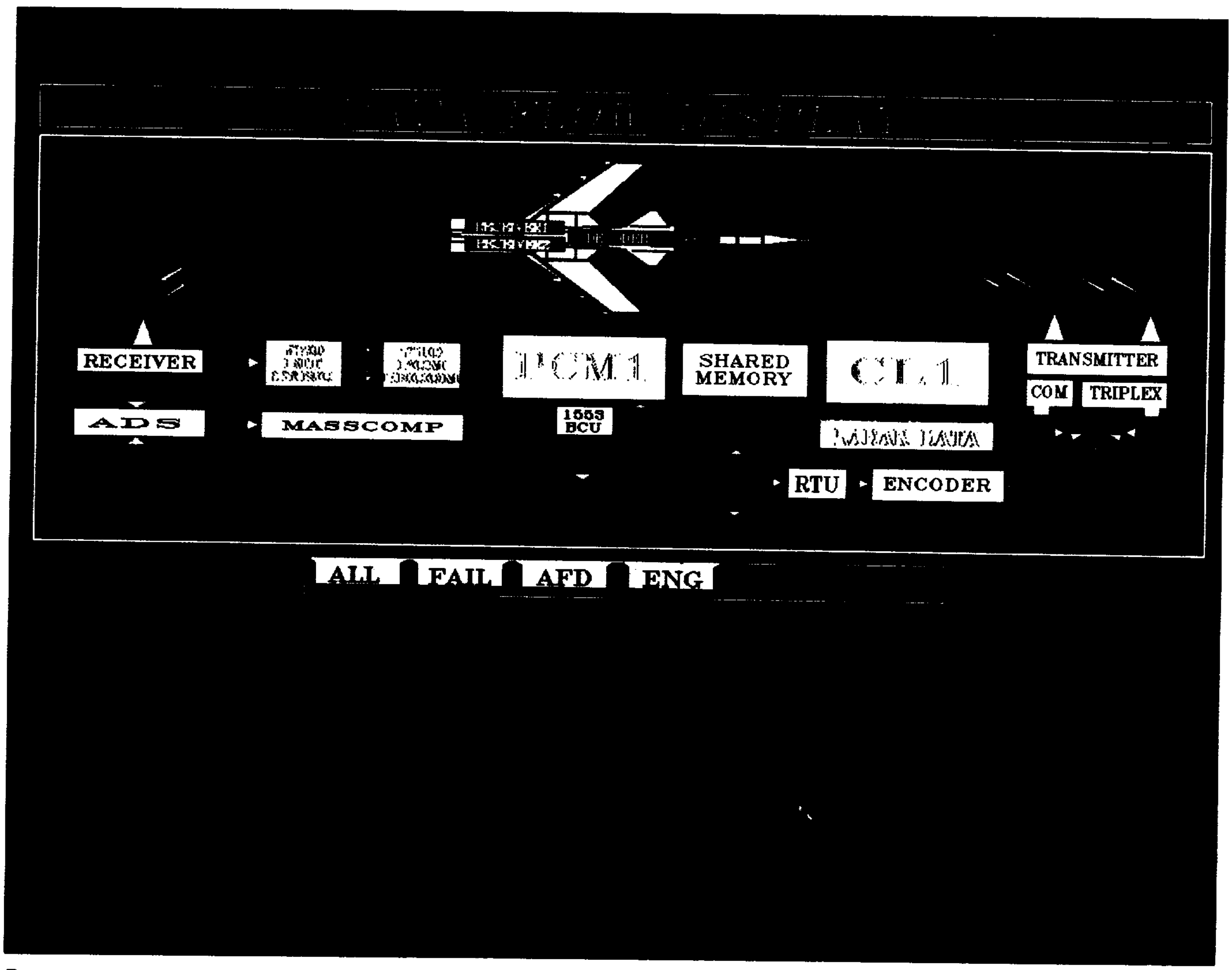
RAVES contains an expert system interface. This manifests itself in two ways, either as a pop-up window or as a fault display. The pop-up window is only used in cases of emergency; it cannot be brought up by the user. The fault window is at the bottom of the screen and continuously scrolls the fault messages.

A unique aspect of the RAVES is the implementation of both Masscomp Graphics Primitives and Visual Intelligence Corporation's Data-Views (DV) graphics displays simultaneously running under the same program. Incorporating two diverse graphics packages in the same program gives the ability to tailor the graphics to the application. For example, the display pages are done in DV-Draw, a MacDraw-like drawing program that is included in DV. This allows engineers with little or no programming experience to design their own displays. The fault window is done in Masscomp Graphics Primitives because speed and not aesthetics is the priority. In this way, the graphics best suited for the job are used.

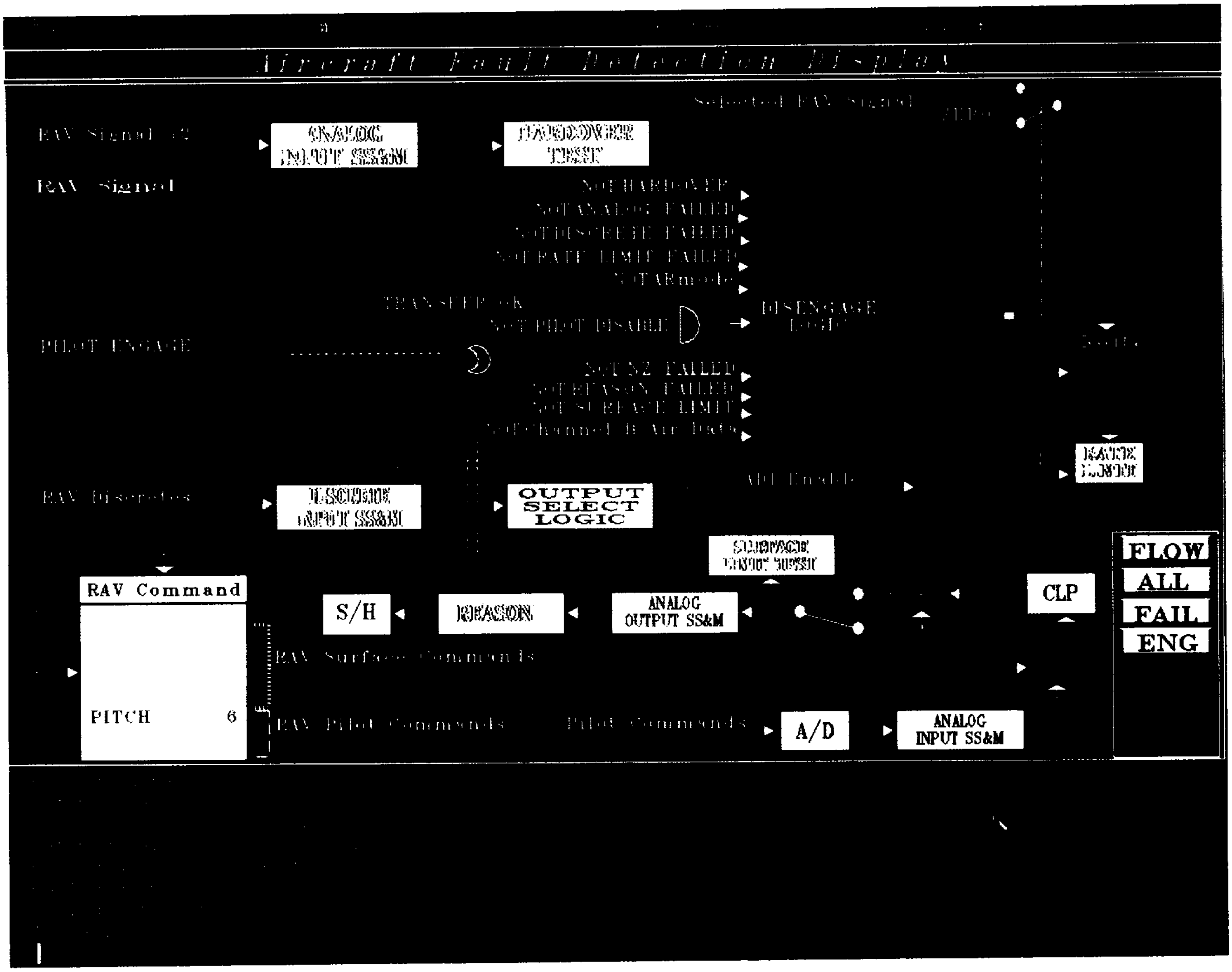
The initial application of the RAVES is to the X-29 Forward-Swept Wing program. Four major displays are used to monitor the X-29 remotely augmented vehicle systems. These displays are

1. All display—displays the majority of the control law and pulse-coded modulation computer parameters, including their failure status and value;
2. Dataflow display—provides a high-level display of the RAV laboratory system (see first figure);
3. Aircraft Fault Detection display—provides a graphical representation of the onboard logic that can cause a disengagement of the RAV laboratory systems (see second figure);
4. Fail display—shows status of the aircraft fault detection system.

Initial tests of the RAVES during X-29 flight tests show a quicker response to failures because of visualization of failure status.



Data flow display



Aircraft fault detection display

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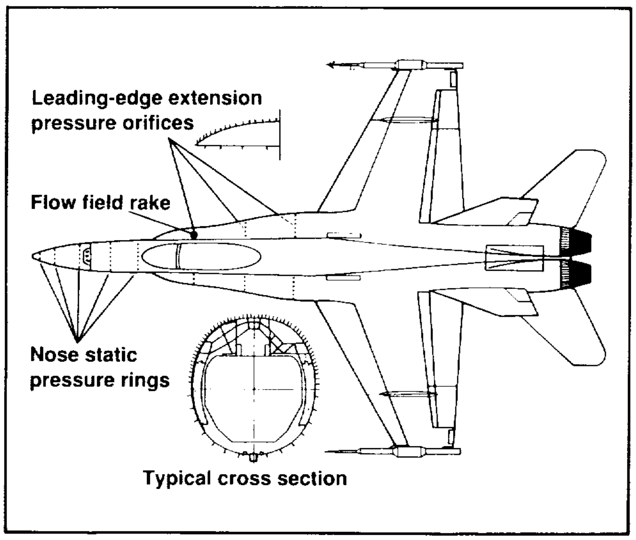
F-18 High Alpha Research Vehicle Pressure Measurements

D. Fisher

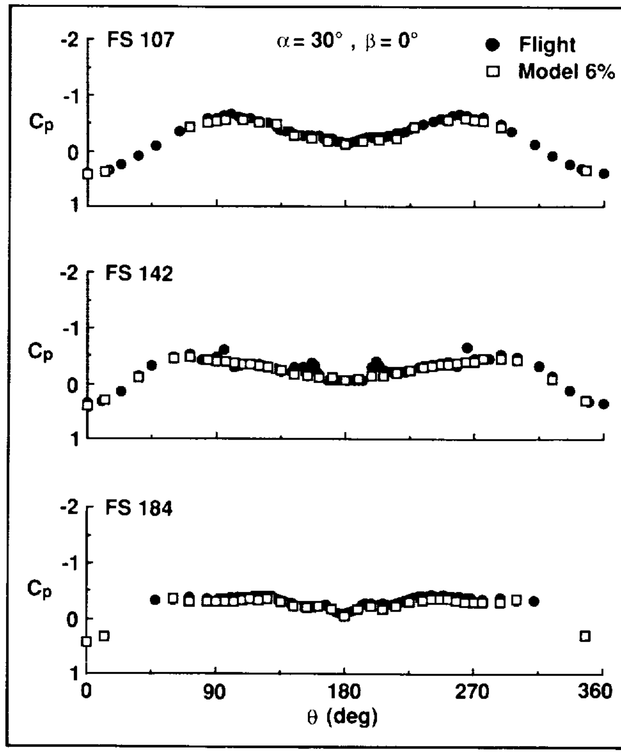
NASA is conducting a High Alpha Technology Program to provide design guidelines and new concepts for vortex control on advanced, highly maneuverable aircraft at high angles of attack. This is a joint program with Ames Research Center-Dryden Flight Research Facility, Ames Research Center-Moffett Field Facility, and Langley Research Center participating. This program, which uses the F-18 configuration as a validation and demonstration approach, consists of wind tunnel tests of sub-scale and full-scale components, calibration for computational fluid dynamics technique codes, piloted simulations, and full-scale flight testing.

As part of this investigation, Ames-Dryden has instrumented the F-18 High Alpha Research Vehicle with five rings of surface static pressure on the forebody and three rows of orifices on the leading-edge extensions (LEX) shown in the first figure.



Location of pressure measurements on NASA F-18 high alpha research vehicle

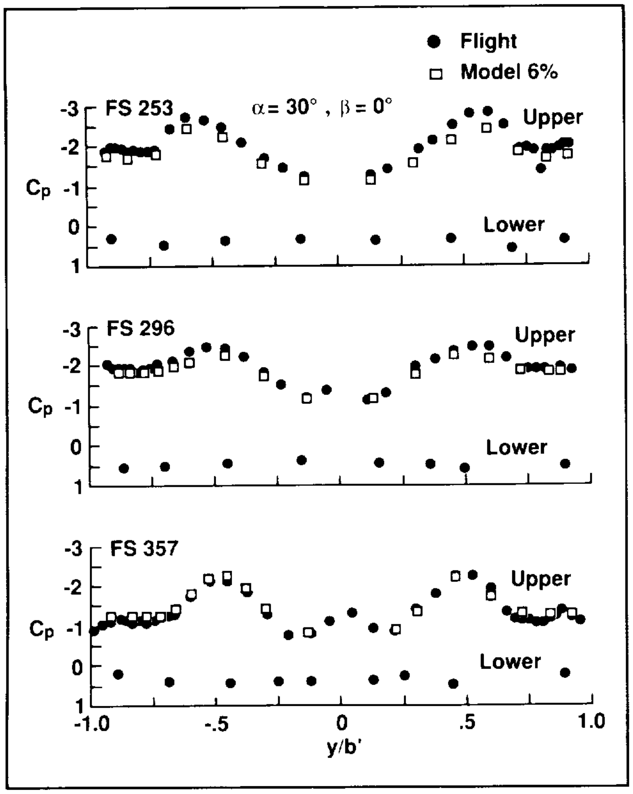
Preliminary flight data for an angle of attack of 30° from three rings of orifices on the forebody are plotted in the second figure in the form of pressure coefficients and radial location. θ is measured from the bottom centerline, 0°, to the top centerline, 180°, and back to the bottom centerline, 360°. For comparison, data obtained from a 6% scale model of the F-18 tested in the David Taylor Research Center's 7- by 10-Foot Transonic Tunnel are included.



Flight and wind tunnel pressure measurements on F-18 high alpha research vehicle forebody

At fuselage station (F.S.) 107, the flight and wind tunnel data show good agreement. At F.S. 142, the flight data show suction peaks at 95°, 156°, 201°, and 265° that are not indicated in the wind tunnel data. The suction peaks at 95° and 265° result from antenna projections on the aircraft and are not represented on the model. The suction peaks at θ = 156° and 201° are very near the location of the secondary vortex separation lines shown by the flight surface flow visualization results. At F.S. 184, these peaks are diminished by the proximity of the canopy.

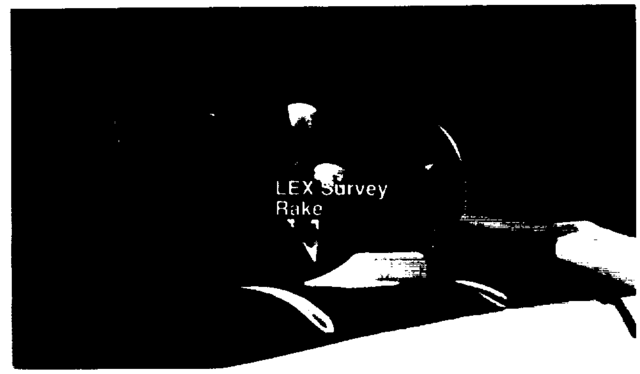
In the third figure, y/b' = 0 is at the LEX fuselage junction and y/b' = ±1 is at the LEX outboard edge. The pressures from the LEXs are plotted as a function of pressure coefficient and nondimensional span location. The pressures on the LEXs from flight show higher suction peaks at F.S. 253 than at the sub-scale model test. The wind tunnel data at F.S. 296 and F.S. 357 show better agreement.



Flight and wind tunnel pressure measurements on F-18 leading-edge extensions

The flight tests to obtain these pressure measurements have recently been completed and the data are being analyzed. Data have been obtained at angles of attack from 10° up to 54° and at sideslip angles exceeding 10°. Data were obtained during stabilized conditions as well as dynamic conditions such as wind-up turn, dutch roll, and wing rock maneuvers.

In addition to the surface measurements, a rotating 16-probe survey rake was mounted on the right LEX near F.S. 253 to map the LEX vortical flow field (see the fourth figure). Each probe consisted of an 0.125-inch diameter 5-port hemispherical head and a ring of static pressures for the measurement of velocities and flow direction. In-flight, the rake was rotated through the LEX vortex system while the aircraft was stabilized at a near constant angle of attack. Previously, the rake probes had been calibrated for flow direction and velocity in the Langley 14- by 22-Foot Subsonic Tunnel. These flight and wind tunnel calibration data have recently been completed and analysis has begun.



Survey rake on right leading-edge extension

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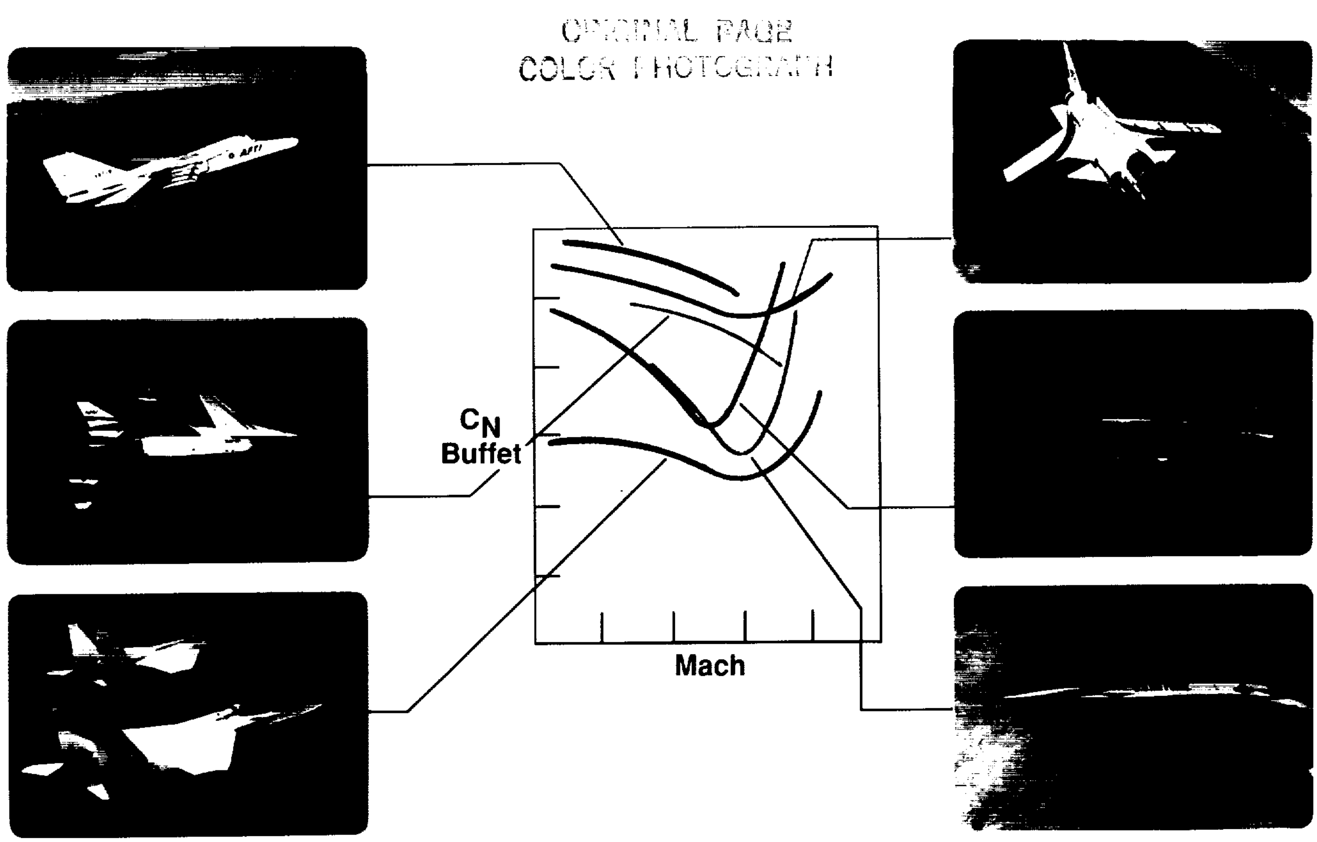
Buffet Studies on High-Performance Aircraft

E. Friend

Superior transonic maneuverability is a prime requisite for modern fighter aircraft. Achieving the necessary amount of useable lift is never an easy design task when considering the angles of attack and resulting turn rate now required. The lift generated ceases to be useable when it is accomplished by unacceptable levels of buffet, degraded handling, or loss of control. Nearly all fighter aircraft have to penetrate beyond the buffet boundary to allow the specified maneuver to be achieved. These requirements emphasize the importance placed on the buffet boundary of an aircraft.

Many advanced technologies are used to increase the aerodynamic performance and are presented in the table. The different technologies shown have varying degrees of strength and weakness depending upon the angle-of-attack levels and Mach numbers under evaluation. In the following paragraphs some differences are discussed.

The buffet boundaries presented in the figure were obtained from flight programs conducted at Ames-Dryden Flight Research Facility. The aircraft



Buffet characteristics on high-performance aircraft

shown, starting from the upper left photo and proceeding counter-clockwise are AFTI/F-111, HIMAT, F-15A, YF-16, YF-17, and X-29.

Direct comparison between airplanes is difficult because of differing definitions of reference areas used in the coefficients; however, the general trends are valid. The data presented are in normal force coefficient form. (It should be noted that because of differences in wing loading for the different airplanes, the normal acceleration experienced for buffet onset may be considerably different than what is shown in coefficient form.)

It is evident from the buffet boundary figure and the table that incorporating supercritical wing technology and maneuver flaps is beneficial at transonic speeds. (Boundaries for the AFTI/F-111, X-29, and HIMAT indicate minimum transonic dip.)

The buffet advantages of the close-coupled canard concepts are masked by the other technologies included. For this concept to be highly successful for moderate angles of attack, the canard aerodynamics including the canard schedule with angle of attack must contain the flow separation on the canard to avoid premature flow breakdown on the wing. The X-29 boundary shown is for the wing only, the canard boundary (not shown) is considerably lower.

AERODYNAMIC FEATURES

Airplane	Supercritical wing technology	Close-coupled canard	Smooth-cambered wing	Maneuver flaps	Leading-edge extensions
AFTI/F-III	X		X	X	
HIMAT	X	X	X		
F-15A			X		
X-29	X	X		X	
YF-16				X	X
YF-17				X	X

The YF-16 and the YF-17 airplanes show large improvements in the boundary for low subsonic speeds. The maneuver flaps are beneficial in improving the boundary. This beneficial effect, however, is less at transonic speeds. It must be recognized that the leading-edge extensions on the wing provide separation-induced vortex flow at the higher angle of attack and actually contain the wing flow separation. This benefit is not realized at the angle of attack where initial buffet occurs.

The boundary for the F-15A airplane in terms of normal force coefficient illustrates a much lower boundary than that shown for the other airplanes. However, the actual buffet boundary (in terms of normal acceleration which the pilot recognizes) is much better than the trend shown in coefficient form. The lower wing loading provides this improvement.

The AFTI/F-111 boundary shows the most improvements. The manuever flap concept incorporates a highly sophisticated smooth-variable camber which can be varied with wing stations. This high buffet boundary is only partially realized in terms of normal acceleration because of the very high wing loading of the F-111 basic design.

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Automatic Camber Modes of the Mission Adaptive Wing on the Advanced Fighter Technology Integration F-111 Aircraft

R. Kempel

The Mission Adaptive Wing was designed and built for the Advanced Fighter Technology Integration F-111 variable-sweep airplane. This wing was designed to provide a hydraulically driven smooth and continuous variable camber of the leading- and trailing-edge flaps as a function of flight condition and/or maneuvering requirement. The wing incorporated flexible fiberglass skins on the top and sliding panels on the bottom to provide smooth, uninterrupted wing surfaces.

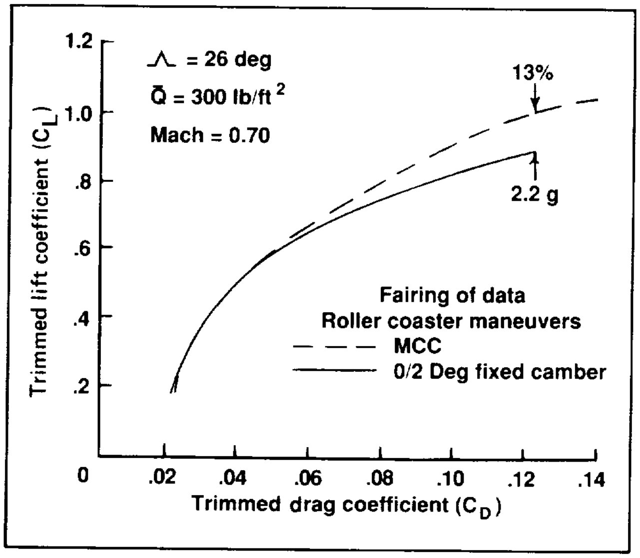
The camber could be changed either manually or by a computer-controlled, dual-redundant, fly-by-wire digitally implemented flight control system. The modes included a manual flight control system and four automatic modes which included the cruise camber control (CCC), maneuver camber control (MCC), maneuver load control (MLC), and the maneuver enhancement/gust alleviation (ME/GA) mode. The CCC and MCC modes were primarily designed to enhance airplane performance. The MLC mode was designed to alleviate wing-root bending loads. The ME/GA mode was designed to enhance the airplane's maneuvering capability and to alleviate the effects of wind gusts as sensed by the flight crew.

The CCC mode was engaged at constant altitude, at constant power lever angle setting, and when the autopilot was engaged. CCC attempted to maximize airspeed by automatically varying wing trailing-edge flaps for a given, manually set, leading-edge flap setting. Analysis of the flight data indicated that CCC was a viable concept; however, refinement of the implementation details such as processing of measurement data was required.

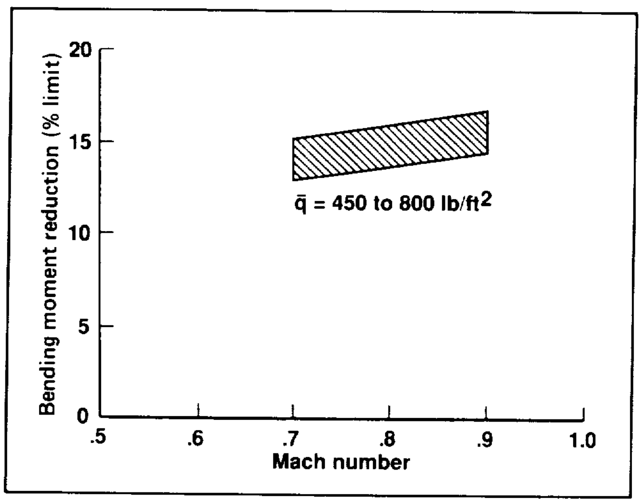
The MCC mode provided a means of improving airplane aerodynamic efficiency by automatically positioning the leading- and trailing-edge flaps at their maximum predicted lift-to-drag ratio positions for either steady-state or maneuvering flight. The commanded leading- and trailing-flap positions were determined based on stored tables of wind tunnel drag polars as a function of wing sweep, Mach number, and lift coefficient. Flight results indicated that MCC showed as much as a 20% increase in lift at the most off design subsonic conditions and a 4% increase at Mach 1.4.

The first figure illustrates typical improvement of MCC as compared with leading and trailing flaps fixed at 0° and 2°, respectively, at a Mach number of 0.7. It should be noted that the MCC performance gains were not fully explored due to airplane operational limitations.

The MLC mode provided the capability of relieving right and/or left wing-root bending moment by command control of the outboard trailing-edge flaps to more trailing-edge-up positions. This mode could be operated in combination with other modes. Variable bending moment threshold values could be selected by the pilot via a threshold select switch. This mode was active only when the bending moment was above the selected threshold value. While MLC was engaged and active, the MLC mode commands superseded any other commands to the trailing outboard flaps. Flight results indicated that MLC reduced wing-root bending moment by 13 to 17% of the limit load which translated to a 0.8- to 1.0-g increase in load factor. The second figure illustrates the load-reduction capability of the MLC mode as a function of Mach number.



Improvement of maneuver camber control as compared with leading and trailing flaps fixed at 0° and 2°, respectively



Load-reduction capability of the maneuver load control mode as a function of Mach number

The ME/GA mode was designed to improve airplane normal acceleration response from the pilot's command and to reduce vertical acceleration at the cockpit because of turbulence. Flight-test results indicated that the maneuver enhancement design objective was met. However, limited flight data indicated that the gust-alleviation portion of the mode showed no measurable improvement nor did the pilots detect any ride quality difference with ME/GA engaged.

This flight-test research program was a joint NASA and U.S. Air Force program conducted at the Ames-Dryden Flight Research Facility at Edwards Air Force Base, California.

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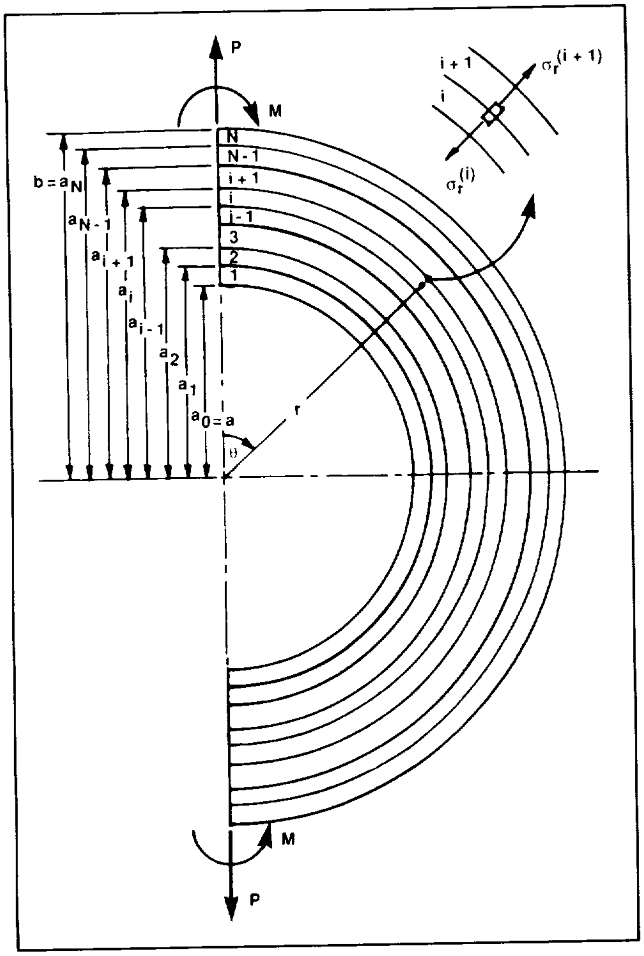
Delamination Analysis of Composite Curved Bars

W. Ko

A major cause of stiffness and strength degradation in laminated composite structures is the delamination between composite layers. In most engineering applications, laminated composite structures have certain curvatures and, therefore, are subjected to potential delamination problems during service (cyclic bending loadings).

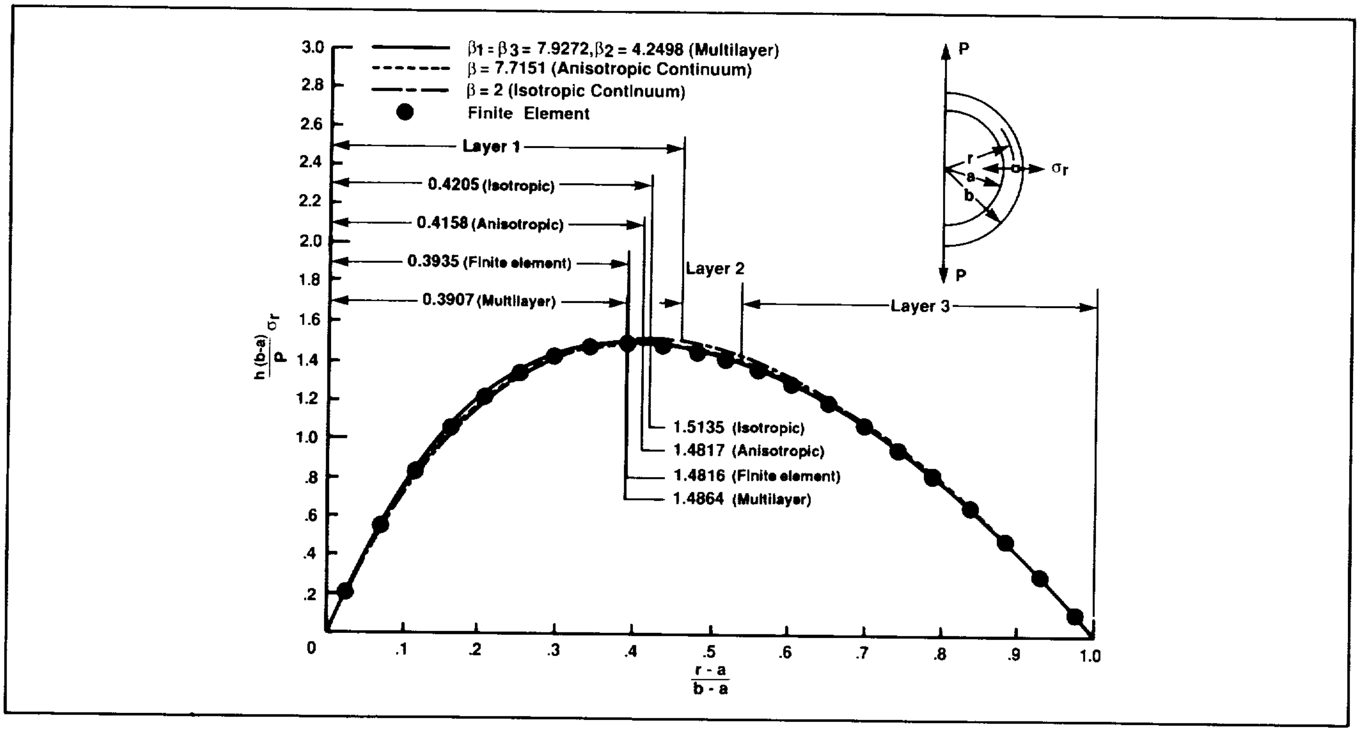
One of the most appealing geometries of test coupon for studying the composite delamination phenomenon is the semicircular curved bar shape (C-coupon). When such a test specimen is subjected to end forces, the peak radial stress and the peak shear stress induced in the curved bar will be identical in magnitude, but are out of phase in the tangential direction by $\pi/2$. Namely, the peak radial stress is located at the midspan point of the semicircular curved bar, but the peak shear stresses occur at both ends of the semicircular curved bar. The radial distance of both the peak radial and the peak shear stresses are exactly the same.

The above nature of the semicircular curved bar offers an excellent situation for studying the initiation and subsequent propagation of delamination zones (open-mode or shear-mode) under cyclic loadings and for studying the fatigue behavior (degradation of stiffness and strength) of multilayered composite materials.

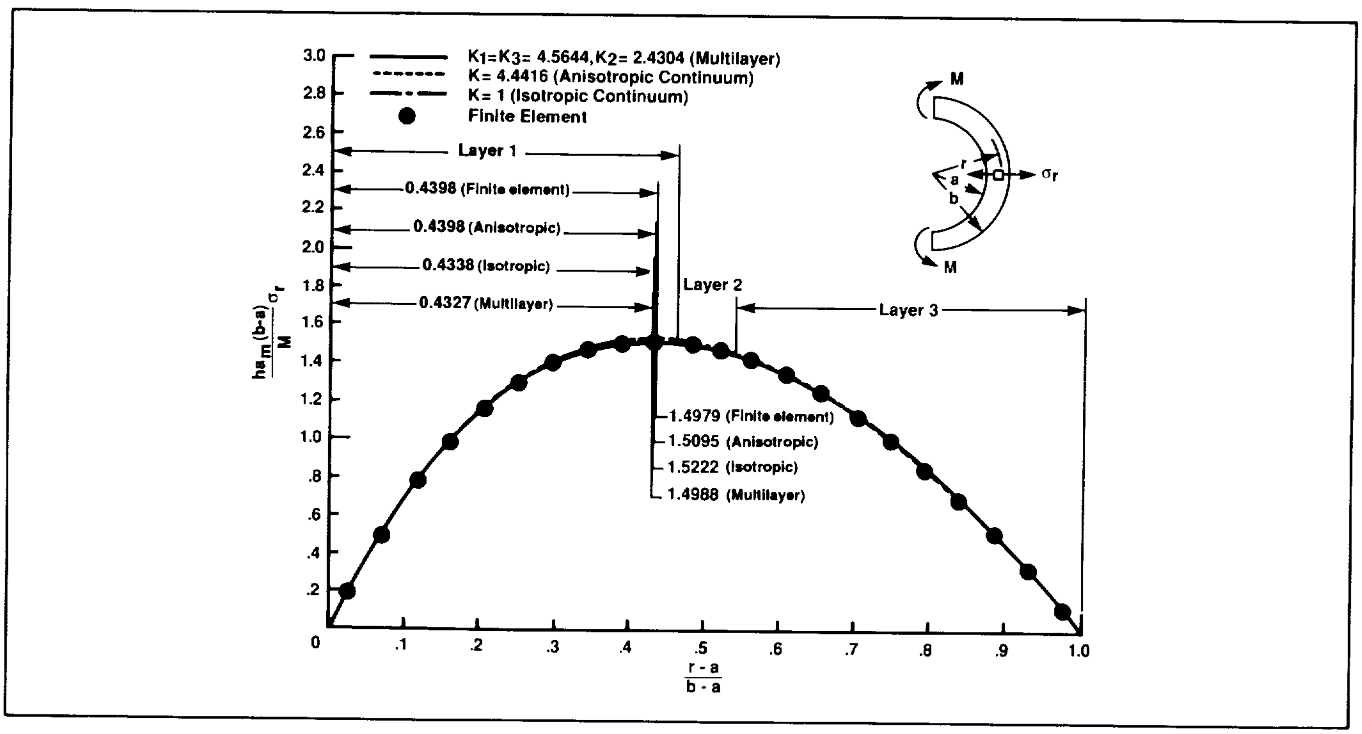


Bending of laminated anisotropic semicircular curved beam by end forces and end moments

The classical anisotropic elasticity theory was used to construct a "multilayer" theory for calculation of the stress and deformation fields induced in the multilayered composite semicircular curved bar subjected to end forces and end moments. The radial location and intensity of the open-mode delamination stress were calculated and compared with the results obtained from the anisotropic continuum theory and the finite element method. The multilayer theory gave more accurate predictions of the location and the intensity of the open-mode delamination stress than those calculated from the anisotropic continuum theory. The "multilayer" theory developed is being applied to predict the open-mode delamination stress concentrations in horseshoe-shaped composite test coupons.



Distribution of radial stress in $\theta = \pi/2$ plane, curved bar under end forces P; b/a = 1.3767



Distribution of radial stress, curved bar under end moments M; b/a = 1.3767

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Integrated Control Flight Research—HIDEC/Inlet Integration and Extended Engine Life Operating Modes

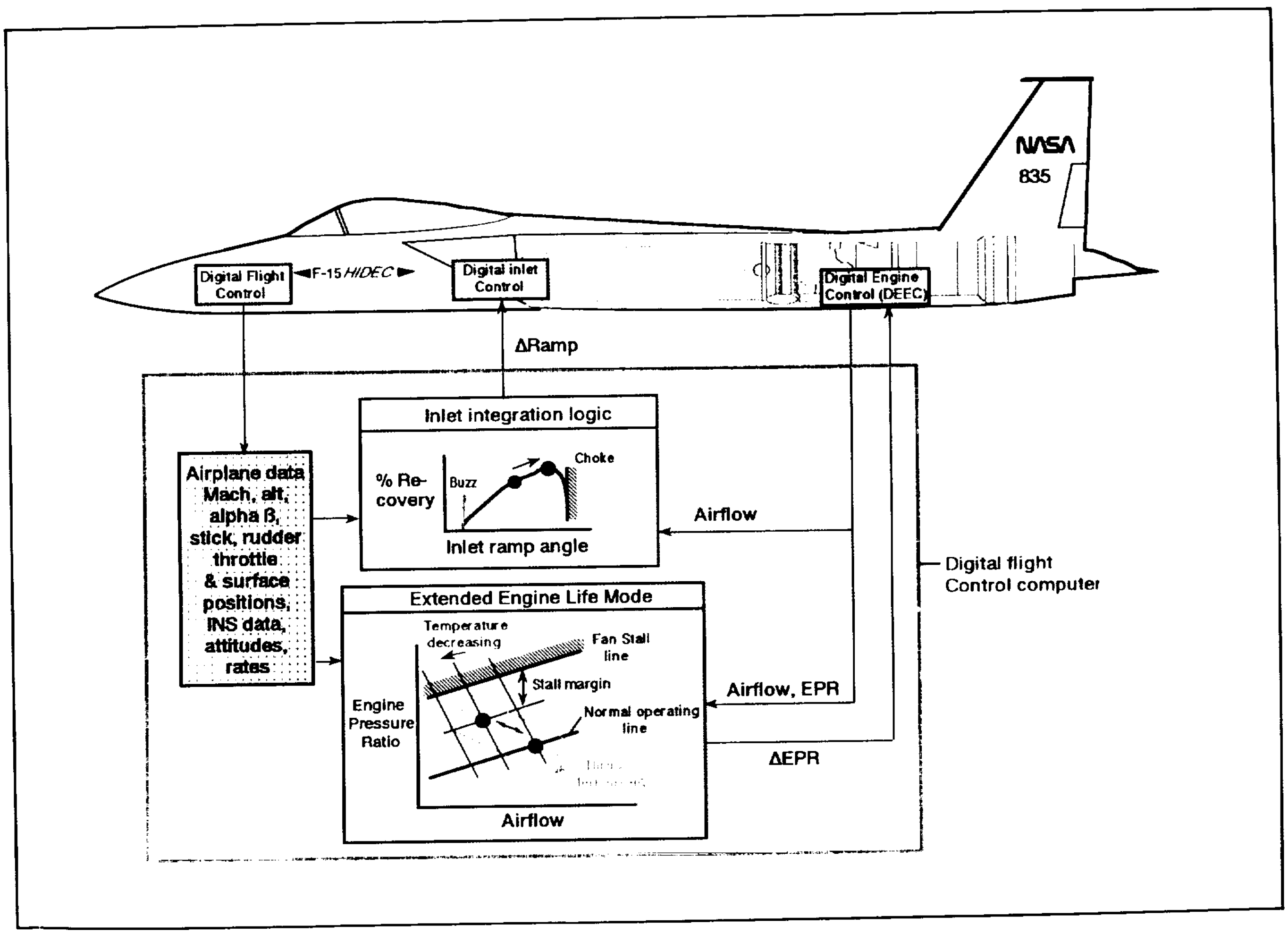
L. Myers

Aircraft performance can be greatly improved with digital electronic controls that integrate the airframe and propulsion systems. The benefits obtained from integrating the flight, engine, and inlet controls may include increased maneuverability, shorter takeoff and landing distances, increased available thrust, decreased fuel use, and extended engine life. The purpose of the NASA Highly Integrated Digital Electronic Control (HIDEC) program is to demonstrate and evaluate the performance benefits that result from control integration.

The NASA F-15 HIDEC airplane is the world's finest integrated-controls flight research facility. The digital electronic engine control (DEEC) systems, the digital air inlet controllers, and the digital flight control system are all integrated as shown in the first figure.

The extended engine life (EEL) mode uses flight control and engine information to lower the turbine operating temperature while keeping thrust constant. The inlet integration (II) mode uses flight control and engine information to improve the real-time scheduling of the inlet ramp positions. In both modes, stability margins may be decreased because the communication between systems permits the calculation of the stability margin needed at any particular instant. Both of these modes were flown in 1989.

The EEL mode operates as shown in the lower block of the first figure. The fan map shows that thrust lines are less steep than temperature lines, so by increasing the engine-pressure ratio and reducing



HIDEC—Engine/inlet/flight control integration the engine airflow, thrust may be held constant at reduced temperature. This operation nearer the fan stall line is modulated in real time on the F-15, and is only possible with an integrated system. The expected benefits of EEL are a lower turbine operating temperature and an improved thrust-specific fuel consumption. The control mode was developed from a nonlinear model of the F-100 engine coupled to an aircraft model.

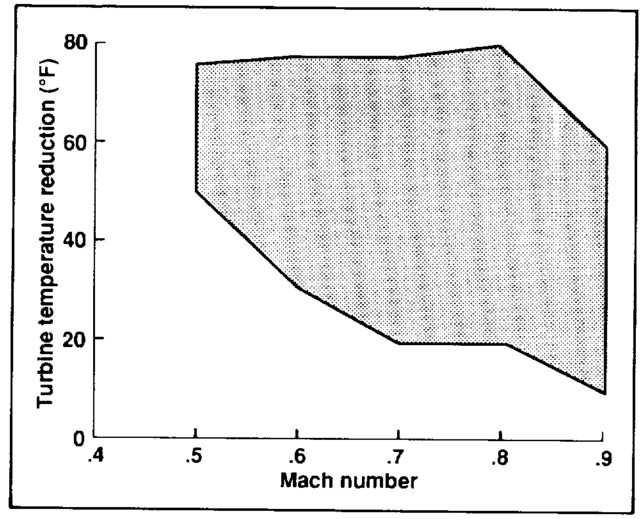
The objective of the II mode was to increase the aircraft and inlet performance by using airplane data and engine airflow data from the DEEC to better schedule inlet geometry. With the additional information, inlet margins could be reduced, operating closer to the choke point. This could result in improved inlet recovery, as shown, and also decreased inlet drag because of a decrease in airflow spillage. A decrease in aircraft trim drag could also be obtained from repositioning the inlet cowl angle, resulting in increased net propulsive force. The optimum schedules for the ramp and cowl were developed from an integrated inlet/engine/aircraft analytical model.

The test approach used to evaluate the HIDEC modes was to perform two runs back to back; to collect, first, the baseline data and, then, the research mode data. Test data were acquired at Mach numbers up to 2.3, and at altitudes up to 50,000 feet.

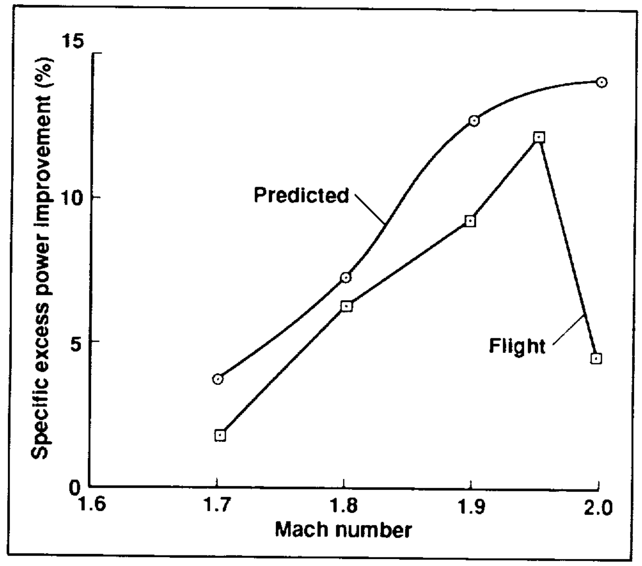
The EEL mode successfully lowered the engine temperature (see the second figure) while holding thrust constant to within 1%. Temperature reductions ranged up to 80°F. The largest temperature reductions occurred at the highest altitudes and lowest Mach numbers. Fuel flow reductions of up to 3% were also found.

The II mode results did not show all the benefits that had been anticipated. The data showed that the inlet scheduling was occurring properly, but increases in thrust were less than predicted.

The differences between the predictions and the flight results are shown in the last figure. At 40,000 feet and maximum power, the flight-measured values of specific excess power are lower than the prediction up to Mach 1.95, and much lower at Mach 2.0. The inlet analytical model, used to develop the inlet schedules is being updated to reflect the flight results.



Extended engine life turbine temperature reductions for military power between 10,000 and 40,000 feet



Inlet integration specific excess power improvement for maximum power at 40,000 feet

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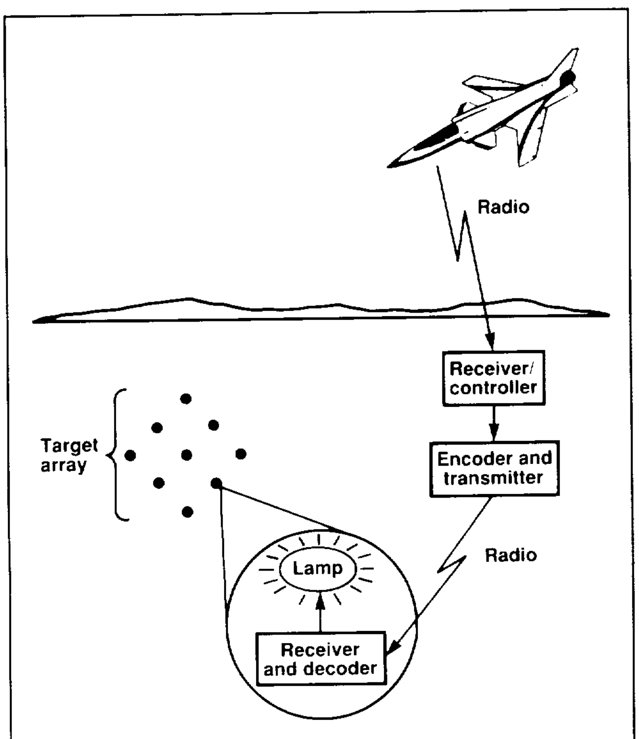
Improved Task for Flying Qualities Assessment

M. Shafer

An improved task for flying qualities assessment has been developed at the Ames-Dryden Flight Research Facility. The task, which simulates the ground-attack task, is implemented with a newly developed ground-deployed system. The Adaptable Target Lighting Array System (ATLAS) is a large array (300 m x 120 m) of targets, as shown in the figure. These targets light in a seemingly random sequence and the pilot has to put the gunsight reticle on the lighted target, while diving at the target array.



General Adaptable Target Lighting Array System layout

The ATLAS system, based on German development, provides a task that is difficult enough to ensure that the flying qualities of the test aircraft are examined thoroughly. The task is repeatable and safe. Clearly defined performance standards make it possible to compare data generated by different pilots. The ATLAS task is well liked by the pilots, who regard it as easy to perform, yet rigorous enough to effectively assess the aircraft.

The ATLAS system has been used with the USAF/Calspan NT-33 Variable Stability Aircraft, the X-29A Forward-Swept Wing aircraft, and the F-15 Eagle. All of these are joint projects with the U.S. Air Force Flight Test Center, Edwards Air Force Base, California. The Air Force has recommended that ATLAS become a standard tool for aircraft flying qualities investigations.

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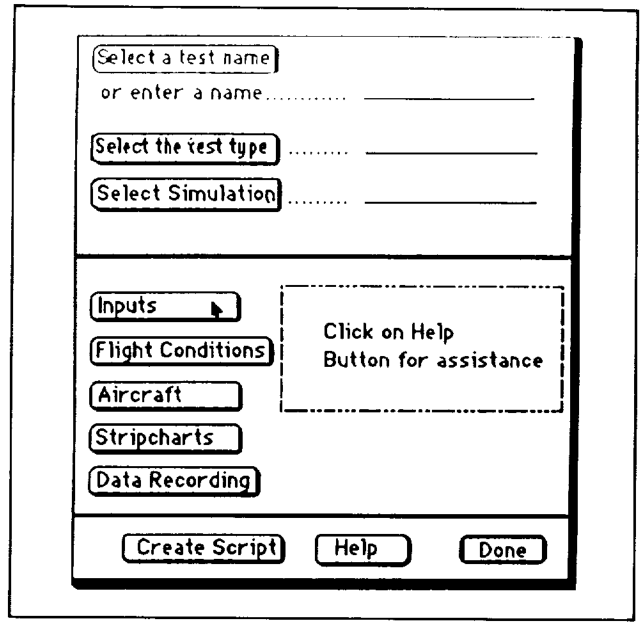
X-29 Automated Testing

J. Sitz, V. Chacon

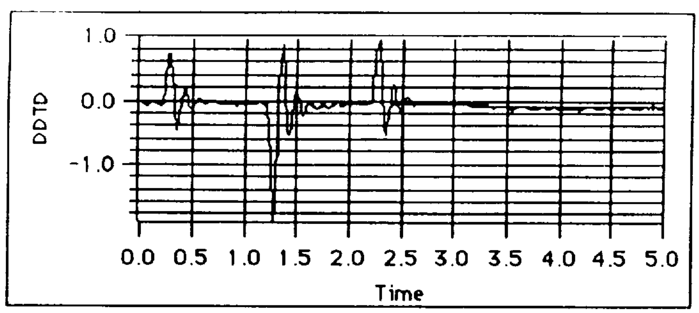
The X-29A project is the first to use a new automated test process developed at Ames-Dryden Flight Research Facility. The goal is to flight-qualify research aircraft with all subsystems operating in a simulated flight environment. The automated test process will significantly increase the number and complexity of tests that can be conducted, while simultaneously it will reduce the time and cost of carrying out the tests. The automated testing system will be used in the Integrated Test Facility under construction at Ames-Dryden.

The first flight qualification tests using the number two X-29A aircraft in a closed-loop simulation were completed in May 1989 at Ames-Dryden. By use of the automated test techniques, the time required to conduct the aircraft flight-control system verification and validation tests was reduced from 4 weeks to 7 days. This equals a labor saving in excess of 7 crew months and allowed the aircraft to be flown 2 1/2 weeks earlier than it would have if the test techniques not been developed. These test techniques are also used in the verification and validation testing of each flight software release. A complex research digital flight-control system (such as that found on the X-29A) may have more than four software releases per year. The potential labor saving for one project alone resulting from the automated testing techniques development is substantial.

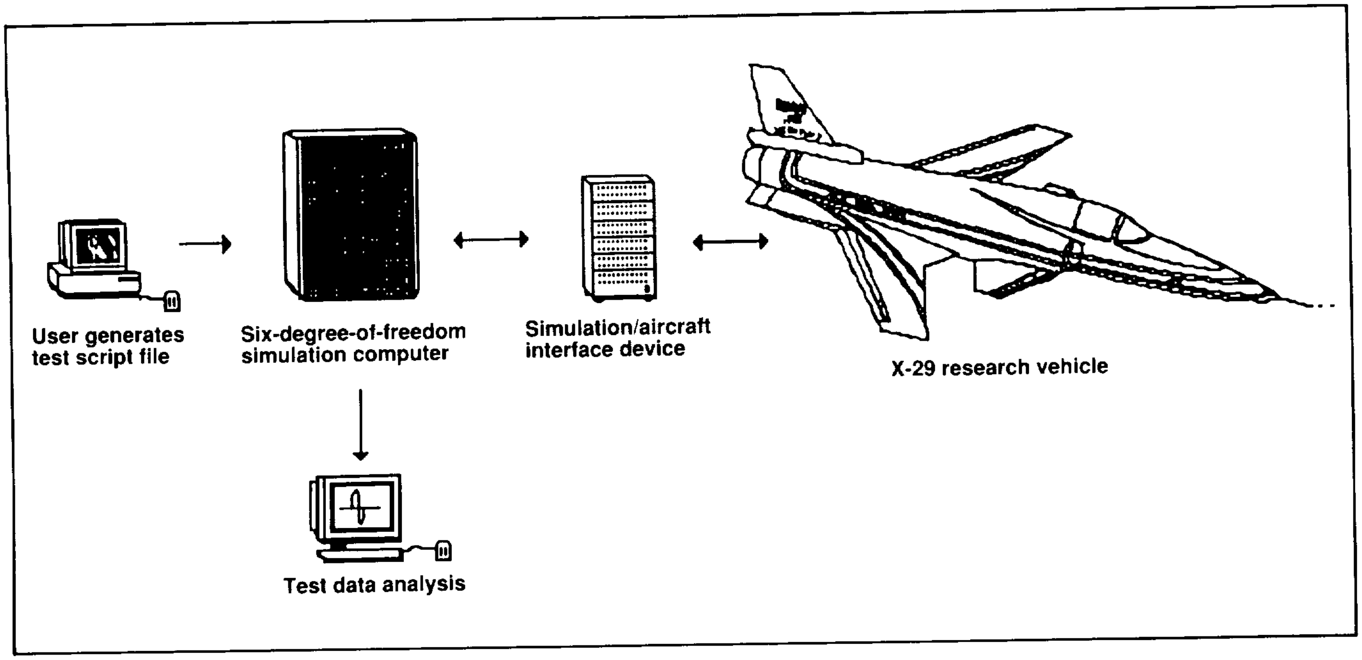
The specific developments contributing to the productivity improvement were English-like scripts that controlled the test equipment, the simulation interface device (SID) and the signal generation capability. The English-like scripts are a means of creating simulation setup and operation command files that can be run by a six-degree-of-freedom simulation. The SID provides a flexible interface between the simulation computers and the aircraft. The signal generation capability allows repeatable test inputs to be summed to any control-system input.



English-like user interface to test equipment



Test results automatically plotted to user terminal



X-29 automated test technique

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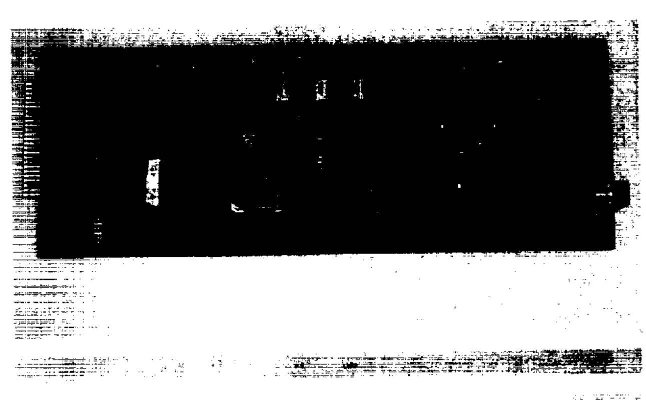
Electronic Device Interfaces Aircraft to Computer

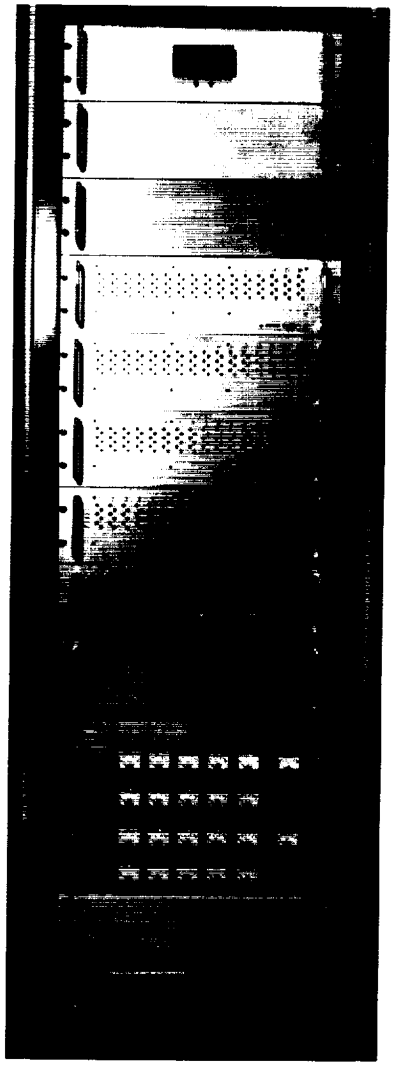
C. Wagner, M. Najera

The Simulation Interface Device (SID) developed at Ames-Dryden Flight Research Facility helps create an environment on the ground that electronically replicates flight for the control systems onboard a modern aircraft. This environment is needed to fully test the aircraft's computerized systems. Working in conjunction with a real-time flight-simulation computer, the SID solves many of the interfacing problems that arise when the aircraft and the computer must communicate via analog lines. These problems include incompatible signal formats, electrical noise, and potential risks of equipment damage caused by interconnection errors.

The SID translates analog and discrete on-off signal formats, provides common mode isolation to reduce electrical noise, and is electrically protected from incorrect connections. It also accepts computer-controlled gain settings, and can electrically disconnect any or all channels from the aircraft on command from the computer. The main SID enclosure is generic in nature, and accommodates a wide variety of project circuit boards designed to meet the unique translation needs of the aircraft being tested.



Typical project circuit board



Simulation interface device

A single SID enclosure can simultaneously handle up to 128 analog and 64 discrete channels. More discrete channels can be added when fewer analog channels are required. Additional SID enclosures can be used when one is insufficient.

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Flight Test Evaluation of a Subsonic High Angle-of-Attack Flush Airdata Sensing (HI-FADS) System

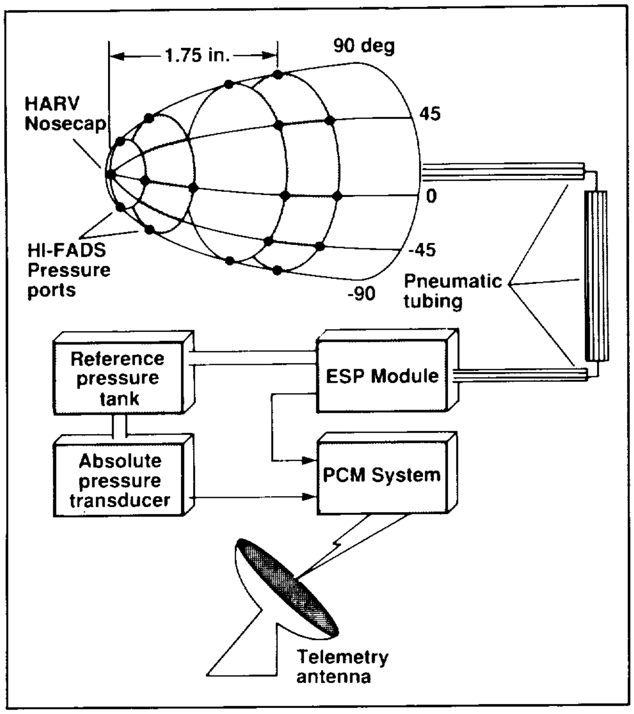
S. Whitmore

Current requirements in aircraft performance maneuver capability have dramatically complicated the problem of flight-control augmentation. This is especially true at high angles of attack where small changes in angle of attack can greatly influence the aerodynamic properties of the aircraft. To study aerodynamics at a high angle of attack, a flight test program with the F-18 High Alpha Research Vehicle (HARV) is being conducted at the Ames/Dryden Flight Research Facility. Preliminary flights have concluded.

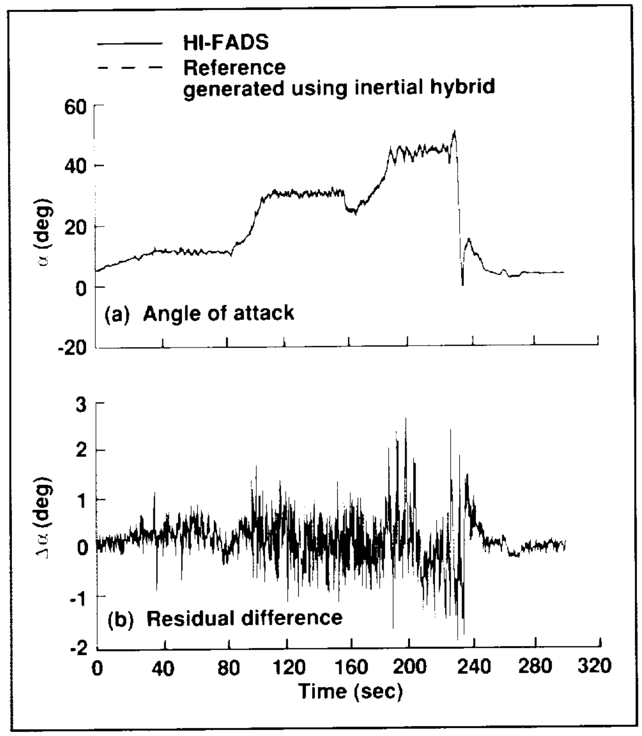
To accomplish the program research objectives, highly accurate airdata measurements were required throughout the entire subsonic flight envelope. At high angles of attack, it is difficult to accurately measure airdata using traditional sensing devices such as nosebooms. Moreover, a nose-boom installation would alter the basic flow characteristics of the aircraft nose. Since flow visualization and aircraft parameter identification at high angles of attack were major HARV program objectives, it was critical that this flow not be altered.

As a means of circumventing this difficulty, a nonintrusive High Angle-of-Attack Flush Airdata Sensing System (HI-FADS) was installed and flight-tested on the HARV. This system, shown in the first figure, consists of a matrix of 25 pressure orifices arranged in concentric circles on the nose of the vehicle for determining angles of attack and sideslip, Mach number, and pressure altitude. Pressure was transmitted from the orifices to an electronically scanned pressure module via lines of flexible pneumatic tubing.

The HI-FADS system was calibrated and demonstrated using flight maneuvers which covered a large range in Mach numbers, angles of attack, and angles of sideslip. Reference airdata for the system calibration were generated using a minimum



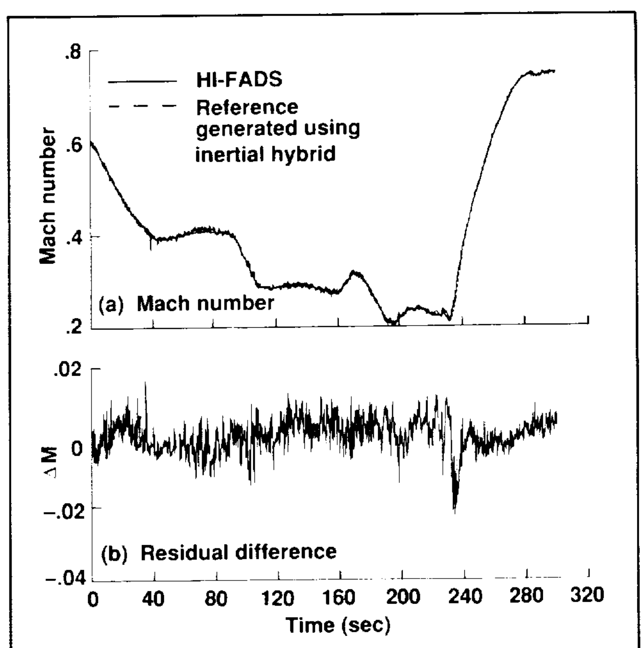
HI-FADS system hardware



Angle-of-attack comparisons

variance estimation technique which blended airdata measurements from two wingtip airdata booms with inertial velocities, aircraft angular rates and attitudes, precision radar tracking, and meteorological analyses. The pressure orifice calibration was based upon identifying empirical adjustments to Modified Newtonian Flow on a hemisphere. Calibration results are presented. The system was demonstrated using all 25 pressure ports and a subset of nine ports.

Under moderate maneuvering conditions, the HI-FADS system provided excellent results over the entire subsonic Mach number range up to 55° angle of attack. Flight test points were obtained for a Mach number range from 0.15 to 0.94 and an angle-of-attack range from −8.0 to 55.0°. Angle-of-sideslip excursions covered the range from −15.0 to 15.0°. Test altitudes ranged from 18,000 feet to 40,000 feet. Comparisons of HI-FADS angle of attack and Mach number to the reference airdata for a typical flight maneuver are presented in the second and third figures.



Mach number comparisons

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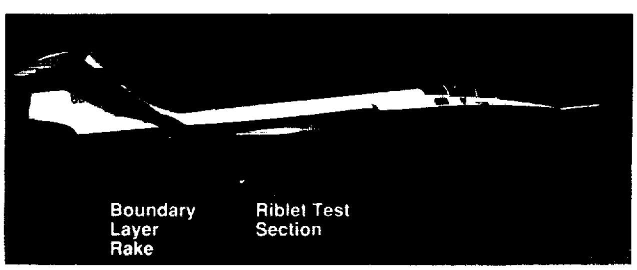
Supersonic Riblet Flight Experiment

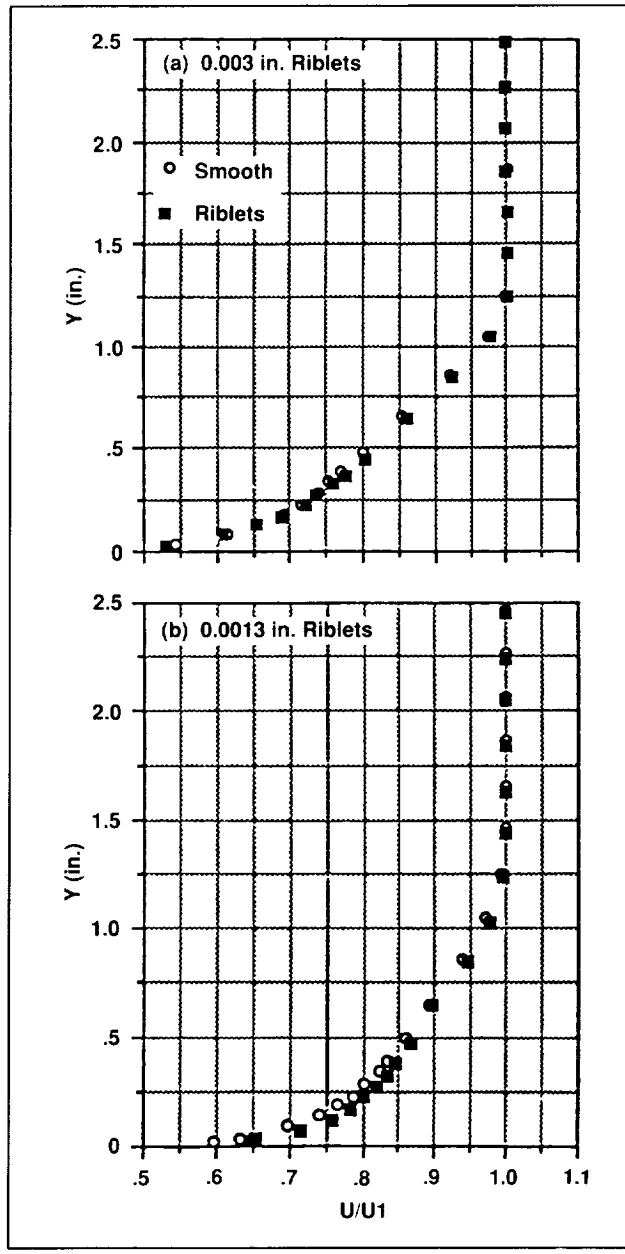
F. Zuniga, B. Anderson

A riblet flight experiment was conducted to test and evaluate the drag-reduction effectiveness of riblets in turbulent flow at transonic and supersonic speeds. Riblets, of groove sizes 0.003 and 0.0013 inches, were mounted and flown on the F-104 Flight Test Fixture shown in the first figure. The 0.003-inch riblets were flown at Mach numbers of 0.7-0.8 and 1.2-1.725 in a unit Reynolds number range of 1.5-3.5 million per unit foot. The 0.0013-inch riblets were flown at Mach number of 0.7-0.8 and 1.2-1.4 in a unit Reynolds number range of 3-6 million per unit foot.

The test sections, shown in the first figure, were surveyed with boundary-layer rakes and pressure orifices used in examining the boundary-layer profiles and pressure distributions of the flow. From the measured differences of momentum thickness, between the smooth and riblet surfaces obtained directly from the boundary-layer data, skin-friction reductions were determined for various test conditions in the transonic and supersonic flight regimes.



F-104 with flight-test fixture

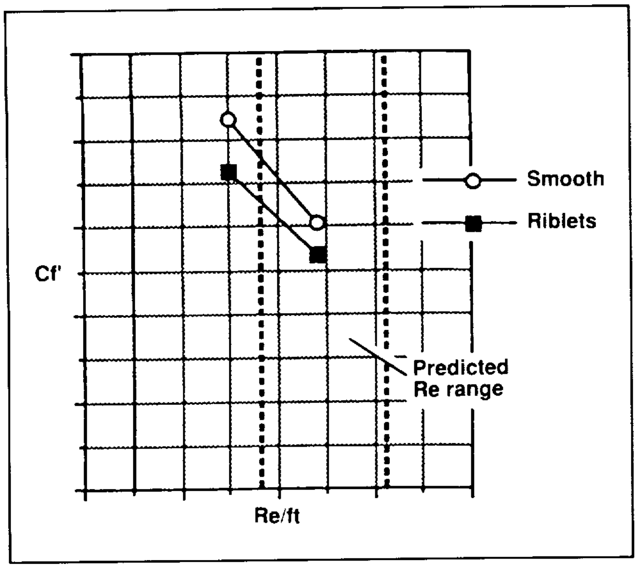


Comparison of smooth and riblet boundary-layer profiles

The second figure shows a typical comparison between the smooth and riblet boundary-layer profiles for the 0.003- and 0.0013-inch riblets which indicates a reduction in the boundary-layer height with the application of the riblet material.

The third figure shows an example of the average skin friction calculated from the flight-test results for the smooth and riblet test surfaces plotted against the unit Reynolds number. These skin friction values are averaged mean results and the prime in the Cf denotes that these skin friction results do not entirely reflect the effect of riblets in reducing skin friction. This is because riblets were not applied to 20% of the surface being surveyed by the boundary-layer rakes, as seen in the first figure. Extracting this upstream flowfield effect from these results leads to preliminary theoretical predictions of 8-10% total skin-friction reduction.

The dashed lines in the plot of the third figure represent the optimum Reynolds number range predicted to yield maximum skin-friction reduction. In



Comparison of average skin-friction results for smooth and riblet test sections

this example, as in many of the conditions evaluated for the 0.003-inch riblets, as well as for the 0.0013-inch riblets, the maximim skin-friction reduction occurred outside of the predicted optimum range. These are the first supersonic flight-test results, and they indicate that riblets are effective in reducing skin friction at supersonic speeds.

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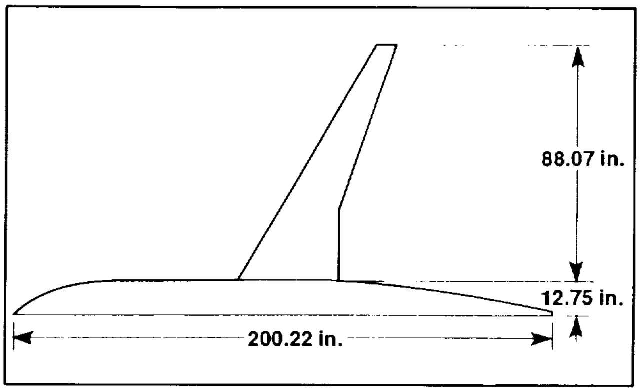
Aerophysics

Euler and Potential Computational Results for Four Transport Wings

S. Cliff, R. Hicks, J. Melton

An Euler code and two potential codes were evaluated for the design and analysis of four commercial transport wings. The codes were evaluated by comparing computations with wind tunnel results from the Ames Research Center 11- by 11-Foot Transonic Wind Tunnel. A planform view of the configuration is shown in the first figure.



Commercial transport wing/body planform

Forces and pressures on the four configurations were obtained during testing. The four wings with identical planforms, but with different wing sections and twist distributions, were tested on a common body. The stainless steel model had eight chordwise rows of pressure taps. Each row had 23 upper-surface and 12 lower-surface orifices. Each of the four wings had 23 defining stations from root to tip.

The sections for the four wings analyzed during this study are shown in the second figure. Note the difference in lower-surface contours between wing A and wings B, C, and D from $\eta = 0.147$ to $\eta = 0.501$. Beyond $\eta = 0.501$ the wing sections become similar with minor differences in thickness.

In practice there is little justification for using the Euler equations in transport wing design because the flight regime of primary interest is transonic cruise, and experience has shown that the full potential equation with a simple quasi-three-dimensional (3-D) integral boundary-layer correction is adequate for this purpose. However, Euler flow solvers have proliferated recently, driven by academic competition, so the aircraft designer needs to determine the range of applicability of such codes.

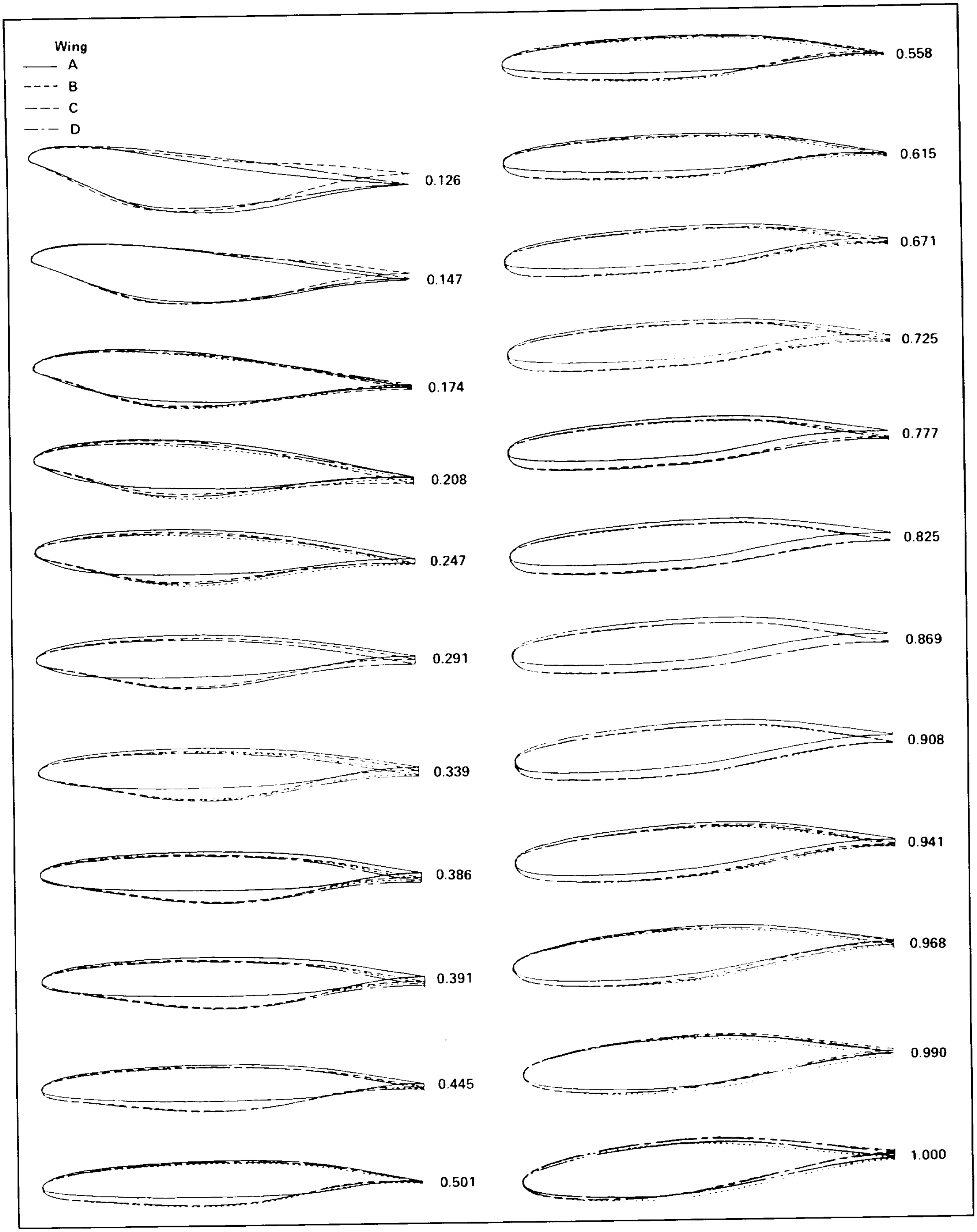
The Euler code, designated FLO57, was evaluated with C-H- and H-O-grid topologies. Extensive computational results were obtained for Mach numbers of 0.40, 0.70, and 0.80 and angles of attack of −2, 0, 2, and 4° for all four wings.

Limited computational results from a fully conservative potential wing-body code and a nonconservative potential isolated-wing code, designated FLO22NM, were also evaluated. The conservative potential code is coupled to a 3-D, finite-difference, boundary-layer code and the nonconservative code includes a quasi-3-D, integral boundary-layer correction.

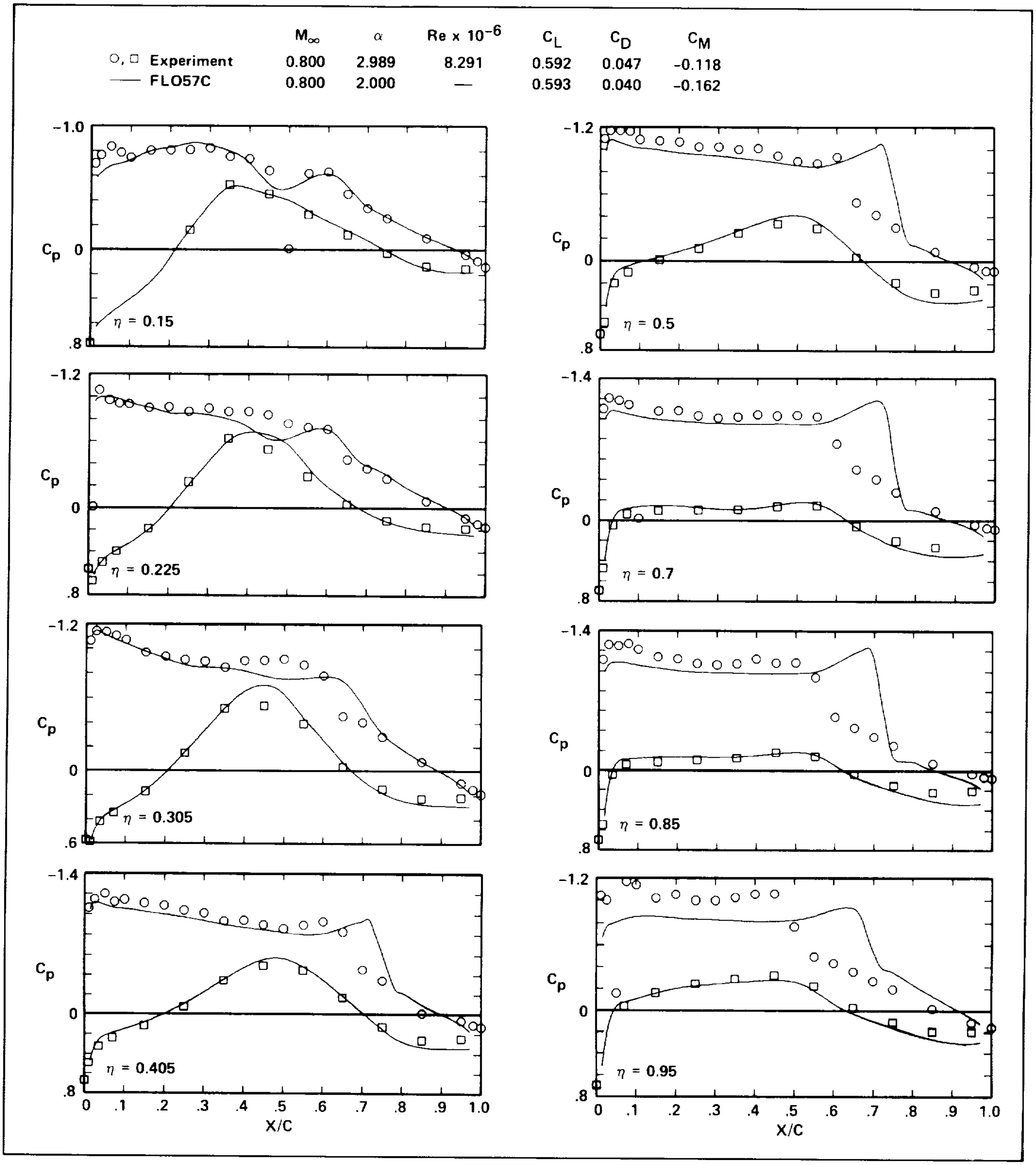
FLO57 was evaluated by two measures. The first is the code's capability of determining quantitative aerodynamic forces, moments, and pressures; the second is the code's capability of ordering the four transport wings correctly with respect to drag level.

The pressure distribution correlations of the Euler computations with the experiment were good for attached subsonic and transonic flow with weak shocks, but were unacceptable for transonic flow with shock waves of moderate strength. An example pressure distribution correlation for wing A near the design condition is shown in the third figure. The shock position and strength are overpredicted by FLO57 as expected since viscosity was neglected. The force and moment correlations using FLO57 were unacceptable at both subsonic and transonic flight conditions, and the Euler code was not able to order the four transport wings with respect to drag.

The isolated-wing, full-potential code, FLO22NM, with a stripwise boundary-layer calculation added, gave better correlation with experimental pressures than the wing/body Euler code, FLO57, without viscous effects. A sample pressure distribution correlation for wing A near the design condition is shown in the fourth figure. Note that the pressures are fairly accurately predicted in spite of the absence

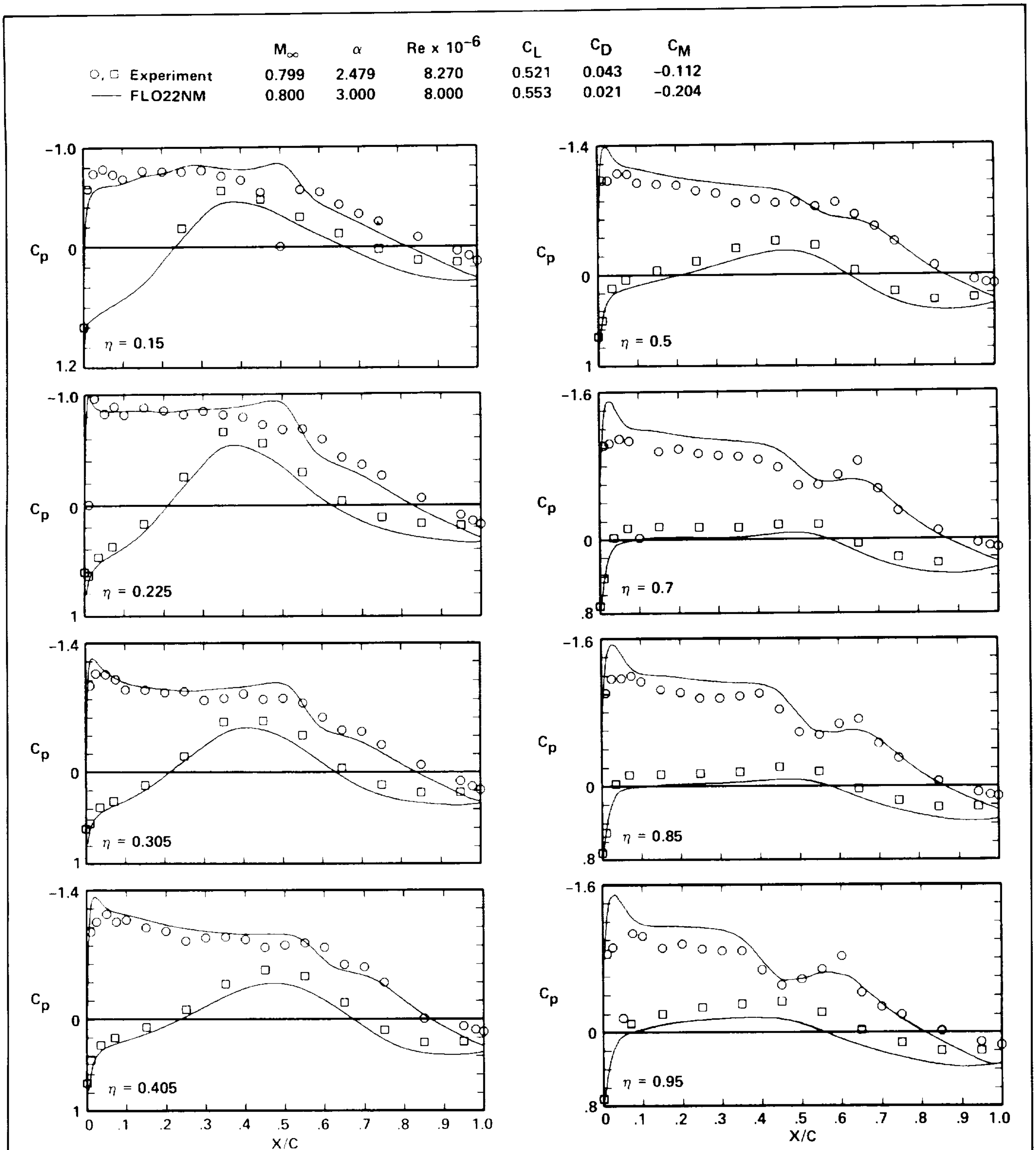


Wing-defining sections



Experiment-CFD pressure distribution comparison for wing A, FLO57

of the body, indicating that viscosity has more effect on the wing surface pressures than on the body. The conservative full-potential, wing-body code coupled to a 3-D finite-difference, boundary-layer program gave satisfactory agreement with experimental pressures for a typical transonic cruise condition.



Experiment-CFD pressure distribution comparison for wing A, FLO22NM

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Drag Improvement Studies of Advanced Propeller Installations

R. Smith, A. Roberts

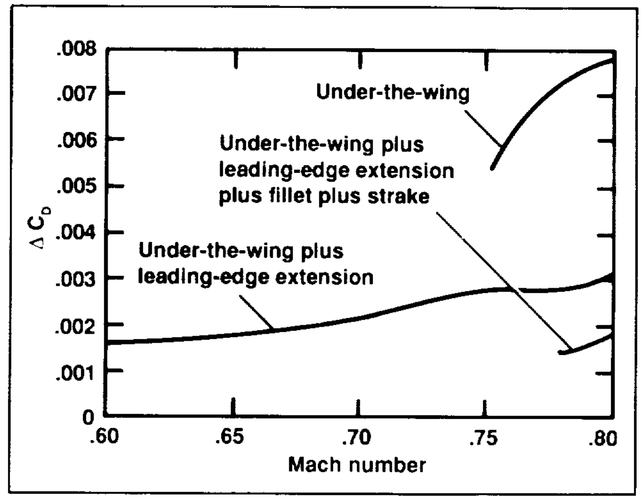
To help establish the feasibility of a new class of fuel-efficient, high-speed (Mach = 0.8), turboprop-powered transports, wind tunnel tests were performed on a series of powered semispan models of candidate propeller/nacelle installations. The studies focused on the installed drag of wing-mounted nacelle configurations which were felt to be particularly sensitive to strong interactions among the nacelle, propeller slipstream, and supersonic flow zone of a supercritical transport wing.

Initial tests were made on a straight nacelle with a single-rotation tractor propeller mounted under a baseline supercritical wing. No attempt was made to integrate the design of the nacelle with the wing except that the propeller axis was aligned with the local wing flow field to minimize cyclic loads on the blades. The drag of this initial baseline arrangement was unacceptably high and studies were initiated to reduce the installed drag of the configuration.

In these studies, a leading-edge extension (LEX) was designed and incorporated into the baseline wing. Subsequently, a fillet and strake were added to the wing/nacelle intersections. The propulsion system drag increment (composed of the nacelle plus the slipstream drag) of these three configurations versus flight Mach number is plotted in the first figure.

This comparison shows the progressive reduction of the propulsion system drag increment at the target cruise Mach number of 0.8 from 0.0078 for the baseline configuration to about 0.0018 for the baseline plus LEX, fillet, and strake. The propulsion system drag levels achieved are, in fact, lower than the estimated skin friction drag of the nacelle alone. These results validated an earlier hypothesis that the angular momentum in the slipstream of a single rotation propeller could be recovered to reduce the drag of the wing in the presence of the slipstream.

Next, the prospect of further drag reduction through recontouring of the nacelle to better integrate with the wing flow field was investigated. Design efforts to recontour the nacelle always

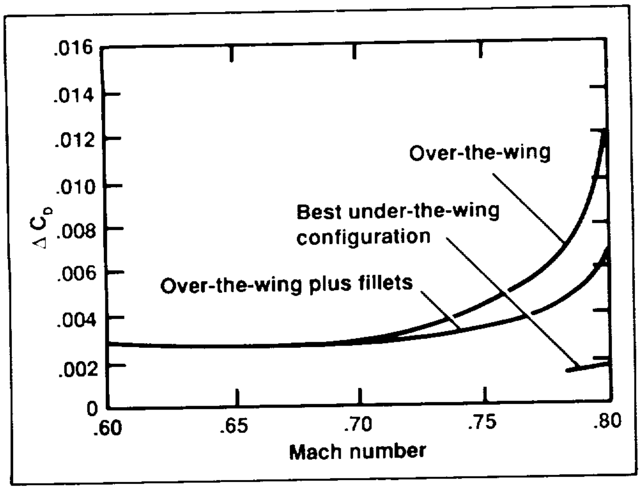


Effects of drag improvement features on the propulsion system drag of the under-the-wing propeller installation

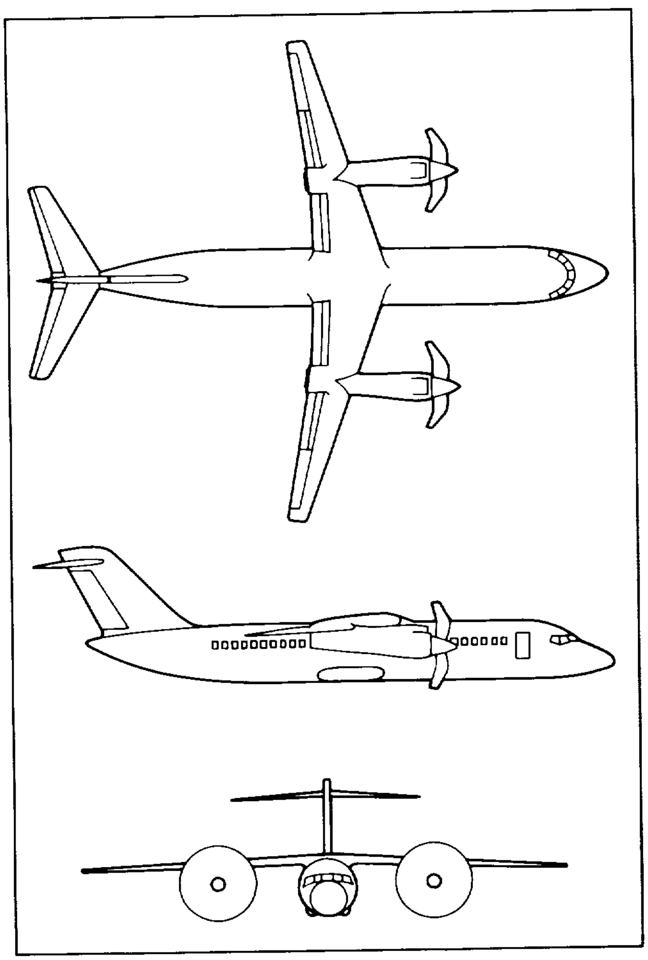
resulted in lowering the position of the propeller relative to the wing. For an under-the-wing installation, such a configuration would have inadequate ground clearance on a low-wing transport, but would be acceptable if the nacelle was moved to an over-the-wing location. An example of this arrangement is the Lockheed P-3 Orion. Alternatively, the wing, with the proven under-the-wing nacelle, could be located high on the fuselage like the current Fokker F-27 and the British Aerospace Hawker Siddeley 146 aircraft.

However, since industry tends to favor low-wing transports, an investigation to integrate an over-the-wing nacelle was initiated, although it was thought to be a much more difficult task because of the supersonic flow above the wing. The expected difficulty in achieving low installed drag was borne out by results of tests on two over-the-wing installations, the better of which did not have satisfactory performance.

Test results for an over-the-wing nacelle carefully integrated with an advanced high aspect ratio (AR ≒ 11) wing are presented in the second figure. The same drag increment used in the first figure is shown versus flight Mach number. As with the under-the-wing arrangement, fillets provided significant drag reduction near the target cruise Mach number of 0.8. However, the propulsion system drag levels are still unacceptably high when compared with the best under-the-wing installation.



Propulsion system drag comparison of the over-the-wing installation with the best under-the-wing configuration



Advanced propeller transport: favored wing mount

These results indicate that the favored wing-mount configuration for the advanced propeller transport should have a contoured under-the-wing nacelle mounted on a high wing. Such a concept is depicted in the third figure. Further work is needed to fully define the potential benefits of this concept to reduce transport fuel consumption.

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Enhancement of Center Computational Resources

M. Smith

During FY 1989, several new state-of-the-art systems were installed in the Central Computer Facility of Ames Research Center, which will enhance the productivity of the Center's scientists. The focus of this activity has been to provide the researcher with a computational environment that improves functionality, offers a uniform programming environment, and presents a common user interface from workstations to supercomputer. The added functionality allows scientists to accomplish computational tasks in less time and with greater ease by removing the barriers created by multiple-vendor systems.

Based on software and graphics standards and the UNIX operating system, this new environment provides the opportunity to incorporate state-of-the-art improvements in a timely manner, thereby enabling the Ames research community to maintain a high level of productivity. It is also expected that these enhancements can be added in a cost-effective manner.

In the area of supercomputer resources, the CRAY X-MP/48 was replaced with a CRAY Y-MP8/832, which increases the computational capacity three to four times. This upgrade includes the integration of the system with networks, mass storage, and support processing systems. The increase in speed and memory enables researchers in computational physics to explore advanced numerical techniques in modeling complex phenomena, such as turbulent flow and composites.

In the interactive computer systems domain, four contracts were awarded to industry leaders for graphics display workstations and mid-range systems. The vendors (Convex, Digital Equipment, Silicon Graphics, and Sun Microsystems) provide a range of capability. They offer state-of-the-art support processing and display capabilities for visualizing numerical solutions and experimental results as well as enhancing the computational power available for projects with specialized processing requirements.

These "requirements contracts" are the result of a single competitive procurement and they provide systems and related support services. A unique feature of each contract allows the addition and/or substitution of products as more powerful and cost-effective systems become available.

The interactive computer systems acquisition has additional benefits for Ames. Researchers can acquire systems with minimal administrative or procurement overhead. Because of the size of this procurement, the vendors discounted their prices for systems and services (more than the typical GSA Schedule discounts), thereby saving Research and Development funds. Support and maintenance for the systems are centralized, resulting in additional savings and responsive delivery schedules. ADP management and security requirements can also be more effectively addressed.

Adoption of the UNIX-based operating system and its integration across all systems means that researchers no longer will have to be proficient with several vendor-proprietary systems to accomplish their computing tasks. Rather, all systems have a common user interface and common utility software, libraries, and display interfaces. The latest capabilities are offered, including full network access, networked file systems, window-type graphical user interfaces, and integration with three-dimensional graphical displays. All of these provide a more effective computational tool.

It is expected that this new environment will significantly increase researchers' productivity. Also, because the new environment is based on government and industry standards, it is expected that acquisition of future hardware systems can be fully competitive and take advantage of new industry developments.

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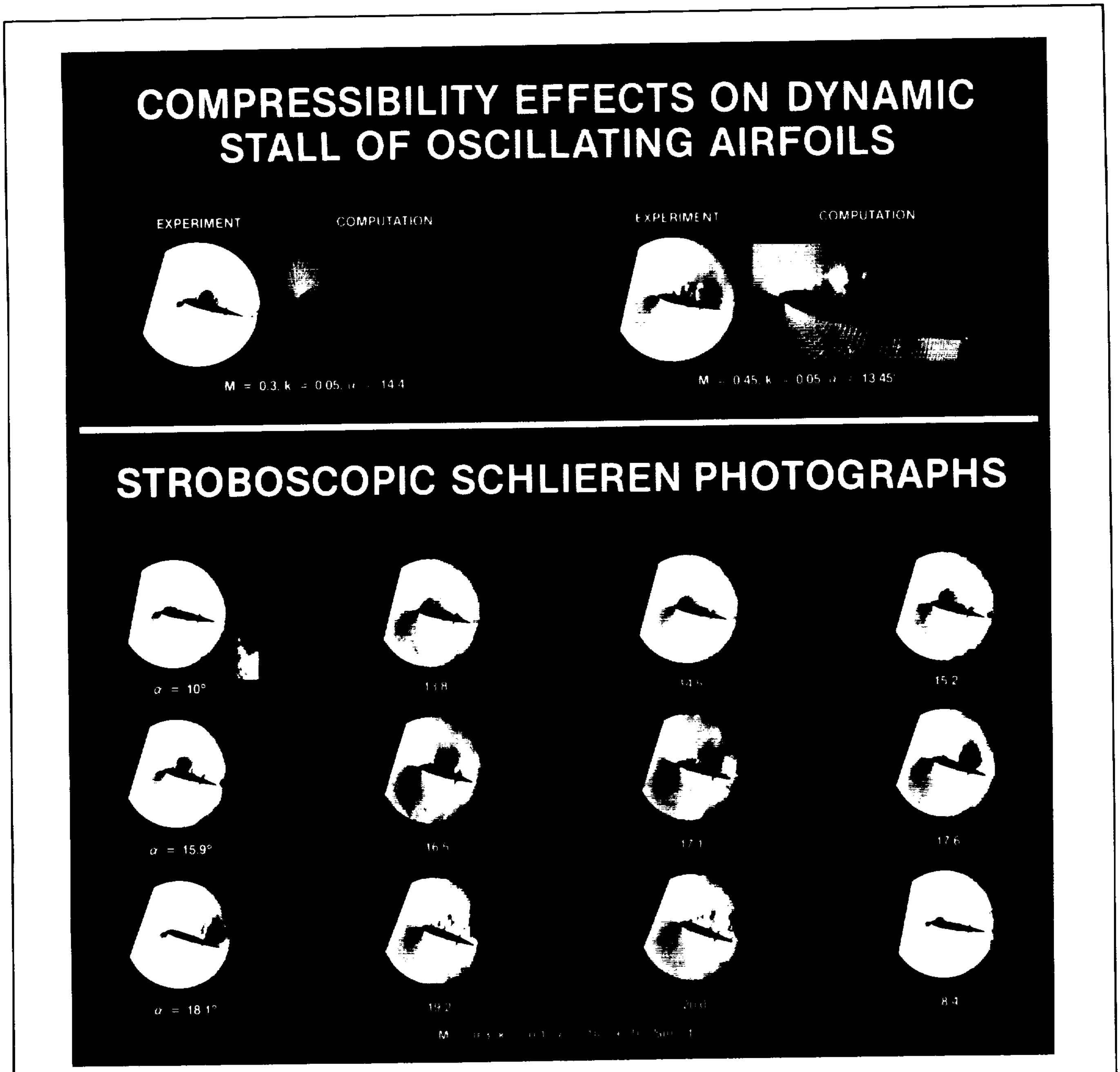
Study of Compressibility Effects on Dynamic Stall

M. Chandrasekhara, L. Carr

Dynamic pitching of wings past the static stall angle can produce significant increases in lift, and can suppress the flow separation which usually leads to loss of effectiveness of control surfaces. However, compressibility can dramatically reduce the potential lift increases that can otherwise be obtained.

To experimentally quantify the dynamic stall behavior of oscillating airfoils as the free-stream Mach number is increased, and to document the unsteady viscous flow field for computational fluid dynamics (CFD) code development and validation, a new Compressible Dynamic Stall Facility was designed and installed in the Fluid Mechanics Laboratory at Ames Research Center. This facility offers the unique capability to obtain a completely unobstructed view of airfoils during oscillation because the airfoil is supported between two optical-quality glass windows that are oscillated in unison so the complete airfoil contour is visible. The facility is capable of varying oscillation frequency up to 100 hertz, corresponding to a reduced frequency of 0.15 at Mach number (M) = 0.5 on a 2-foot chord control surface.

The effect of Mach number on the vortex location and structure on oscillating airfoils has been determined visually and has been compared to results calculated using advanced CFD techniques. A direct comparison between experiment and calculation can be seen in the figure, where the results for M = 0.3 and M = 0.45 are presented for a high



Comparison between experimental results and results calculated using CFD techniques of the effect of Mach number on the vortex location and structure on oscillating airfoils

reduced frequency at the instantaneous angle of attack of approximately 14°. A sequence of stroboscopic schlieren images that depict the growth and convection of the dynamic-stall vortex is also presented in the figure.

New insight into compressibility effects on the dynamic-stall process was obtained in this initial phase of study of dynamic-stall development on oscillating airfoils in compressible flow (all previous research of this detail was restricted to incompressible flow phenomena). The ability to observe the stall development in compressible flow greatly increases the potential for control of the development of dynamic stall on helicopters, and can lead to dramatic improvements in control of fighter aircraft during rapid maneuvers as well.

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Detailed quantitative studies of the unsteady velocity field using laser Doppler velocimetry, holography, and other advanced diagnostic techniques are in progress. These will provide much needed data on flow-field quantities that will enable optimized control of this unsteady flow field to be accomplished, and will enable development of improved CFD codes for guidance of future engineering technology development.

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Efficient Solution Capability for Hypersonic Flows

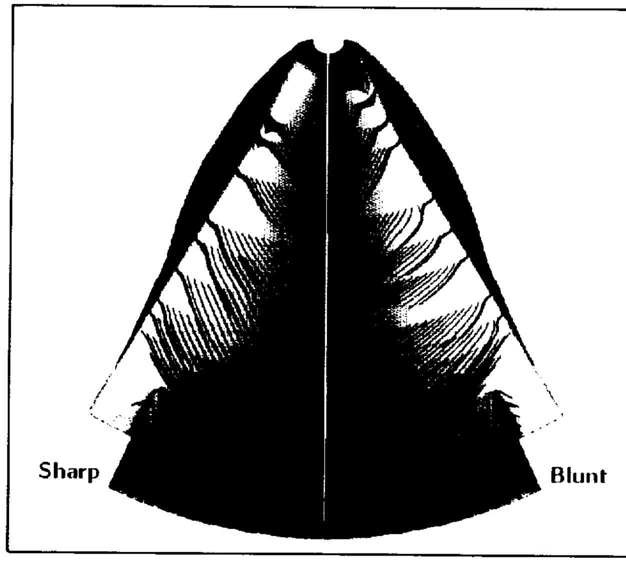
T. Edwards, S. Lawrence

The Applied Computational Fluids Branch at Ames Research Center is developing two computational fluid dynamics (CFD) computer programs for use in hypersonic flow problems. Though their initial application is to the National Aero-Space Plane, they are applicable to a wide range of vehicle geometries and flow conditions. The two codes use different physical approximations which are appropriate in different regions of a hypersonic flow field; hence, the two methods must be coupled to give a complete picture. However, by employing these approximations, the solution procedure is greatly simplified and computer run times are correspondingly reduced.

A parabolized Navier-Stokes (PNS) solver is used for portions of the body that do not generate regions of reverse flow or detached shock waves. For these types of flow fields, PNS solvers are desirable because solutions can be generated with a single-sweep space-marching procedure. The present PNS code uses an upwind algorithm in the crossflow directions to enhance the resolution of embedded shock waves.

Regions of a flow field that contain streamwise separation or subsonic post-shock Mach numbers are computed with a time-dependent Navier-Stokes solver. This code uses a partially upwind (upwind in one direction) algorithm applied within a zonal framework. In the zonal approach, multiple grids of simple topology are patched together to produce the grid for a complex configuration.

In 1989, equilibrium and finite-rate air chemistry effects were incorporated into both of the codes described. In addition, an interfacing procedure was developed to allow the codes to be used in tandem. In this procedure, results at the outflow plane of the time-dependent solution are interpolated onto the PNS grid to provide the initial condition for the space-marching calculation. This interface is necessary for the analysis of blunt-nosed vehicles because of the subsonic region near the tip of the bow shock. Results of such a calculation are shown in the figure.



Computed oil flow pattern indicating the effect of nose bluntness

The simulated oil flow pattern for the case in which the nose is blunt is compared with a sharp-nose case computed using the PNS code alone. Bluntness greatly increases the degree of boundary-layer crossflow toward the body centerline. The configuration is the McDonnell Douglas generic option blended-wing-body; the free-stream conditions, chosen to match an experimental study of this geometry, are Mach 11.3 flow at a Reynolds number of 9.7 million per foot. The body is at zero incidence to the free-stream flow.

A similar interfacing procedure can be applied at the downstream plane of a PNS calculation to provide upstream boundary conditions to the time-dependent code for calculating a complex feature such as an engine inlet. The long-term objective of this effort is to develop the capability for simulating the entire flow field, external and internal, associated with a vehicle in powered hypersonic flight.

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Navier-Stokes Computations on Flexible Wings

G. Guruswamy

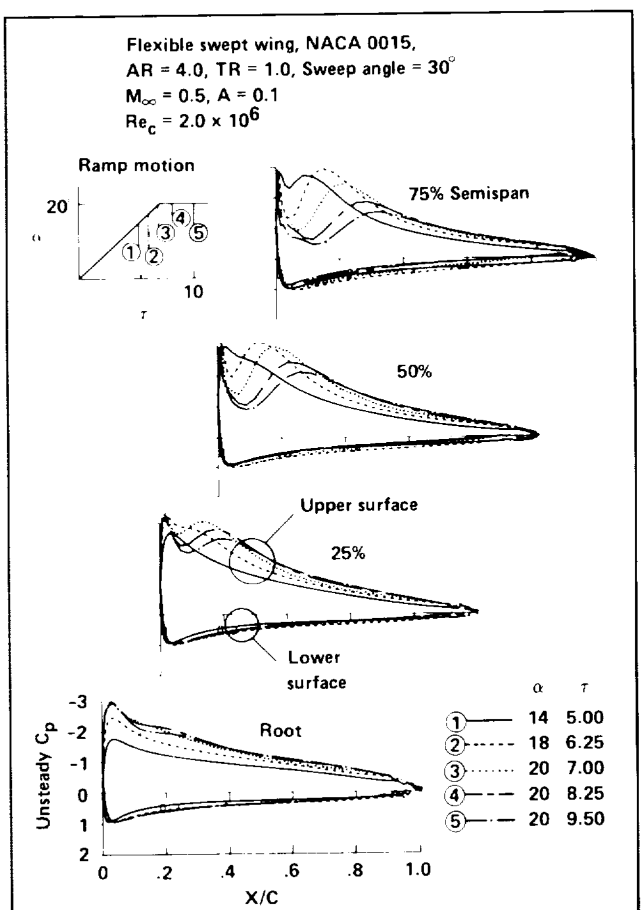
Understanding the nature of flows and their interaction with structures is becoming more important for aircraft, particularly for fighters. High performance and maneuverability are playing major roles in the design of fighters. Flows over fighters are quite often complex, and are associated with vortices and shock waves. Formation of vortices changes the aerodynamic load distribution on a wing. Vortices formed on aircraft have caused several instabilities such as wing rock and aeroelastic oscillations for highly swept wings. Such instabilities can severely impair the performance of an aircraft.

To accurately compute flows and their interaction with structures, it is necessary to solve the Navier-Stokes equations and couple them with the structural equations. Such efforts have begun at Ames Research Center and, in 1988, methods were developed to accurately couple the Euler solutions with the structural equations. They are incorporated in a generic aeroelastic code, ENSAERO.

In 1989, the capability of ENSAERO has been extended to model the Navier-Stokes equations. Currently, ENSAERO 2.0 computes aeroelastic responses by simultaneously integrating the Euler/Navier-Stokes equations and the modal structural equations of motion for wings by using aeroelastically adaptive dynamic grids. The flow is solved by time-accurate, finite-difference schemes based on the Beam-Warming algorithm. Using ENSAERO, computations were made for swept flexible wings to demonstrate the effects of vortical flows.

The figures demonstrate the effects of vortical flows on flexible wings. The first figure shows the vortex-dominated unsteady pressures on a flexible wing undergoing ramp-type motion. The second figure shows the presence of a leading-edge vortex at the end of the ramp motion on an aeroelastically deformed wing.

In this project, the Navier-Stokes equations are successfully coupled with the modal structural equations of motion for advanced aeroelastic applications. With this new computational tool, practically important aeroelastic phenomena such as vortex-induced wing oscillations can be studied. This work has advanced the state of the art of computational fluid dynamics applications to aeroelasticity. ENSAERO will be further extended to model full aircraft and complex aeroelastic phenomena associated with vortical and separated flows will be studied.



Vortex-dominated unsteady pressures on a wing in ramp motion

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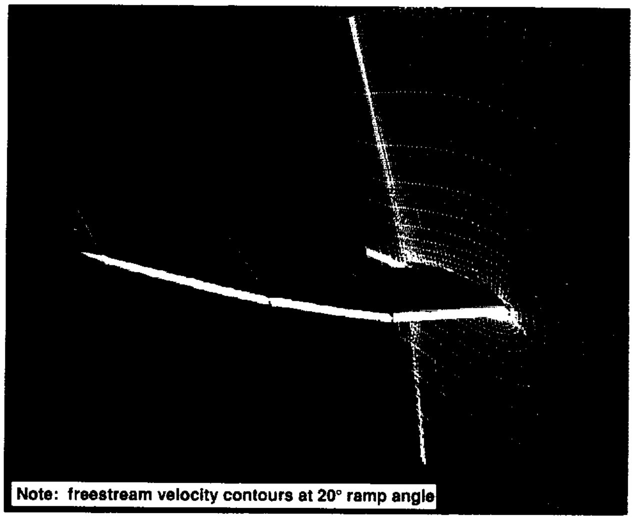

Vortex-dominated velocity contours on aeroelastically deformed wing. AR = 4.0, NACA 0015 sections, sweep angle = 30°, M = 0.5, Re = 2.0x10^6, pitch rate = 0.1

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Hypersonic Shock-Wave/ Boundary-Layer Interaction Flows

C. Horstman, M. Kussoy

A shock-wave/turbulent-boundary-layer interaction study has begun in the Ames Research Center 3.5-Foot Hypersonic Wind Tunnel.

The test model, shown in the figure, is sufficiently large to generate fully developed turbulent boundary layers ahead of the interaction at Mach numbers up to 10. Both two-dimensional (as shown in the figure) and three-dimensional interactions are being studied.

The measurements include surface oil flow, pressure, skin friction, and heat transfer. Also detailed mean flow surveys through the boundary layer are obtained with probes attached to a traverse mechanism located within the model. The results will be used for code validation and compressible turbulence modeling studies.

In addition to the experimental work, a companion compressible turbulence model-development program is under way. Initial results show that standard models are inadequate for predicting these complex flows at hypersonic speeds. Computed results using proposed compressible modifications agree well with the experimental results.

Hypersonic test model

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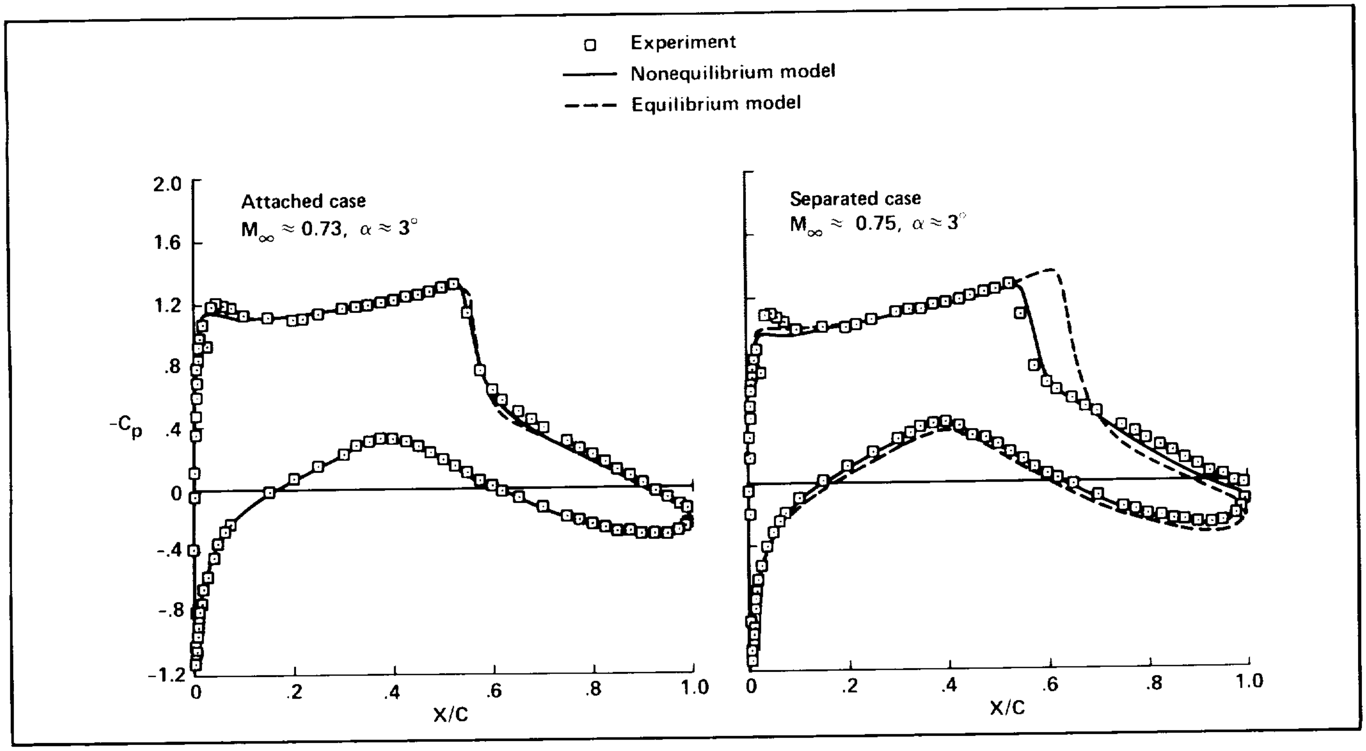
Improvement of a Nonequilibrium Algebraic Turbulence Model

D. Johnson, T. Coakley

In the calculation of the complete flow about an aircraft or an aircraft component (including the thin viscous layer that develops along the surface), some form of turbulence model is required. Recently, a nonequilibrium algebraic turbulence model was proposed, based on knowledge gained from experimental studies in the transonic speed range. This nonequilibrium turbulence model yielded significant improvements in predictive accuracy over previous turbulence models for difficult transonic airfoil test cases.

In these test cases, the shock waves on the upper airfoil surfaces were sufficiently strong to cause the viscous layer along the airfoil surface to thicken rapidly and the flow immediately next to the surface to flow backward (to separate). Quite surprisingly, however, the performance of this nonequilibrium model for easier test cases with weak shock



Predicted and experimental surface pressure distributions for the RAE 2822 airfoil at transonic conditions

waves and no separation was not as good as that of earlier models. The reason for this anomaly was determined and the turbulence model was modified. As a result of the modification, substantial improvements in predictive accuracy for weak shock-wave cases are attainable while the predictive capabilities previously demonstrated for strong shock-wave cases are retained.

The figure compares the performance of this modified nonequilibrium model for both a weak shock wave (attached flow) and a strong shock wave (separated flow) transonic airfoil test case. Included in this figure are results obtained with a popular equilibrium algebraic model. Similar performance improvements have been demonstrated for transonic wing flows.

This turbulence model is expected to be used extensively in Reynolds-averaged Navier-Stokes calculation methods for transonic wing design.

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Computational Aerodynamics for Rotorcraft Applications

W. McCroskey, J. Baeder, E. Duque

For several years, a joint NASA/U.S. Army effort has been under way to develop and extend modern computational fluid dynamics (CFD) methodology to the complex three-dimensional, unsteady flow environment of helicopters and advanced rotorcraft. In 1989, this effort came to fruition in two important areas of application: (1) the calculation of the developing aerodynamic and acoustic fields of a rotating blade interacting with a strong, concentrated vortex generated by the tip of another blade, and (2) the detailed study of the flow fields on the tips of complex but effective blade tip shapes.

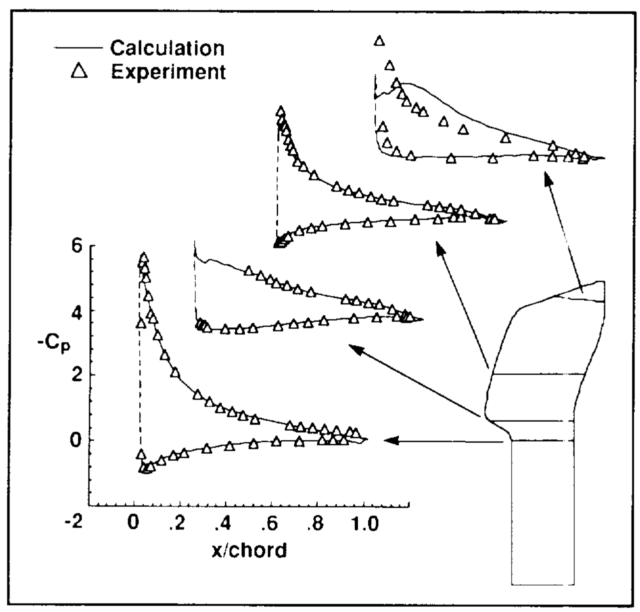
For calculations of helicopter blade-vortex interaction (BVI), advanced CFD methods were developed to solve the unsteady Euler equations under locally transonic flow conditions. Good agreement was obtained with surface pressure distributions measured on an instrumented model rotor.

Two- and three-dimensional calculations revealed details of the BVI encounter that had not been seen before, including the nonlinear evolution of the unsteady pressure field around the blade into radiating acoustic waves. The most important parameters of BVI were found to be the strength and proximity of the impinging vortex and the local Mach number of the blade element. For interactions in which the core of the vortex was approximately parallel to the leading edge of the blade, three-dimensional effects were found to be much more important in transonic than in subsonic cases. On the other hand, the radiated noise was found to be relatively insensitive to the shape of the airfoil of the blade. Sikorsky Aircraft and Bell Helicopter Textron (BHT) used Ames Research Center's two-dimensional codes to analyze BVI noise under the auspices of the NASA/American Helicopter Society Rotorcraft Noise Reduction Program.

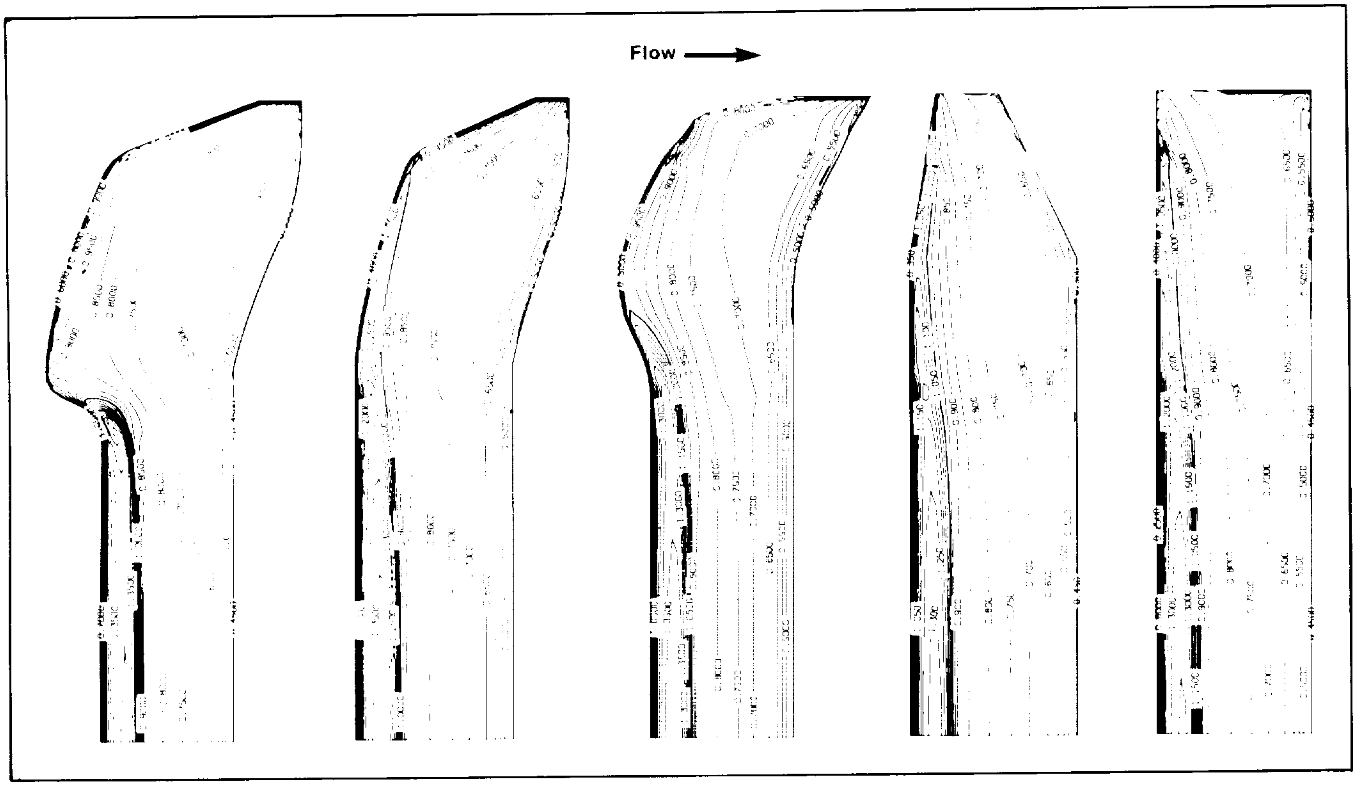
Detailed studies were made of the flow fields around advanced blade-tip geometries, including the extremely complex, but effective blade of the British Experimental Rotor Program (BERP) that was used on the Westland G-Lynx helicopter that currently holds the world speed record. Two different Ames codes that solve the compressible full-potential and the Reynolds-averaged, thin-layer Navier-Stokes equations were used to analyze the BERP blade and six other configurations of interest in three flow regimes: (1) subsonic flow at low and moderate angles of attack, (2) low-speed stalled flow, and (3) transonic flow at low angles of attack. The numerical studies were performed at Ames and at BHT; the latter fell under the auspices of a NASA/BHT memorandum of understanding.

In addition to the lift, drag, and pitching-moment characteristics of the blades, detailed pressure distributions and surface flow behavior were studied. The first figure shows a comparison of computed and measured pressure distributions on the nonrotating BERP blade. The second figure shows iso-Mach lines on several of the blades studied.

In these studies, the favorable stall delay and reduced shock-strength features of the BERP blade were identified and quantified with respect to other tip shapes.



Surface pressure validation; M = 0.2, Re = 1.5×10^6, α = 13°



Surface Mach contours, inviscid method, M = 0.6°, α = 6°

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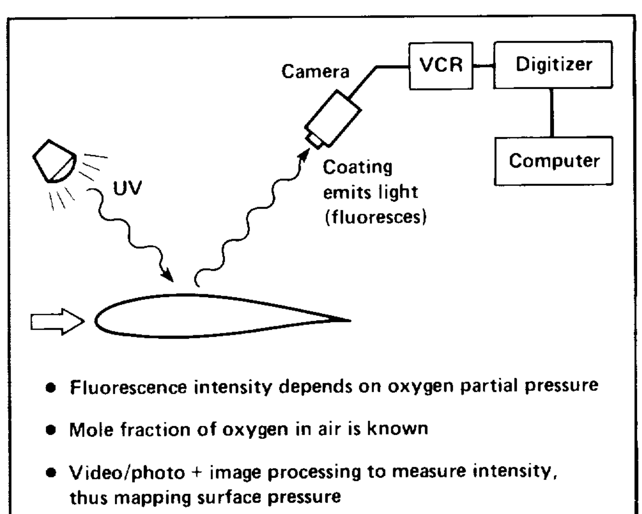
Surface Pressure Field Mapping Using Luminescent Coatings

B. McLachlan, J. Kavandi, J. Callis

Recent experiments demonstrated the feasibility of using the luminescent phenomenon of oxygen quenching for surface pressure measurement in aerodynamic testing. This technique is based on the observation that for many luminescent molecules, the light emitted increases as the oxygen partial pressure the molecules experience decreases. A knowledge of the oxygen partial pressure allows the air pressure to be readily calculated since the mole fraction of oxygen in air is known.

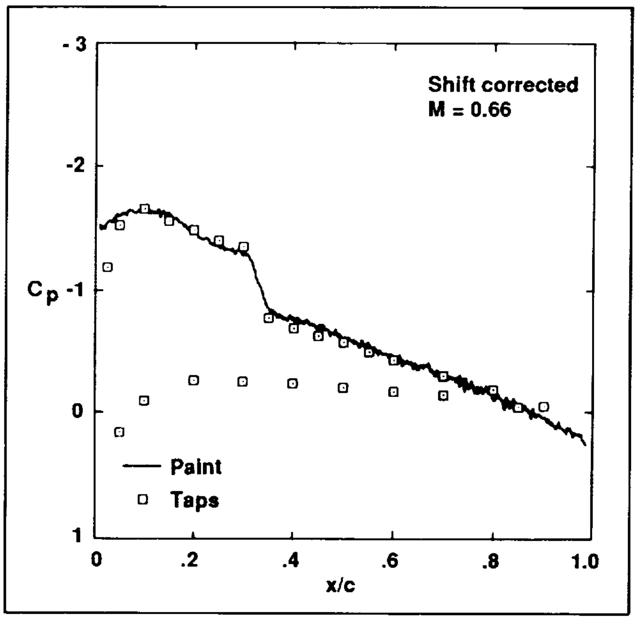
In practice (see first figure) the surface to be observed is coated with a luminescent molecule and



Luminescent-coating pressure sensing system is illuminated with ultraviolet radiation. The airflow-induced surface pressure field is seen as a luminescence-intensity distribution which can be measured using quantitative video techniques. Computer processing converts the video data into a map of the surface pressure field.

The experiments consisted of evaluating a trial luminescent coating in measuring the static surface pressure field over a two-dimensional NACA-0012 section model airfoil for Mach numbers ranging from 0.3 to 0.66. The trial coating was developed by J. L. Kavandi, J. B. Callis, and M. Gouterman of the University of Washington. The luminescent-coating-derived pressures over the upper surface were compared to those obtained from conventional pressure taps.

A typical comparison is shown in the second figure. The luminescent coating accurately captured all features of the pressure distribution except in a small region at the airfoil leading edge.



Comparison of luminescent coating to conventional pressure tap measurements: mid-span chordwise pressure distribution, Mach = 0.66

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Simulation of Unsteady Multiple-Body Aerodynamics

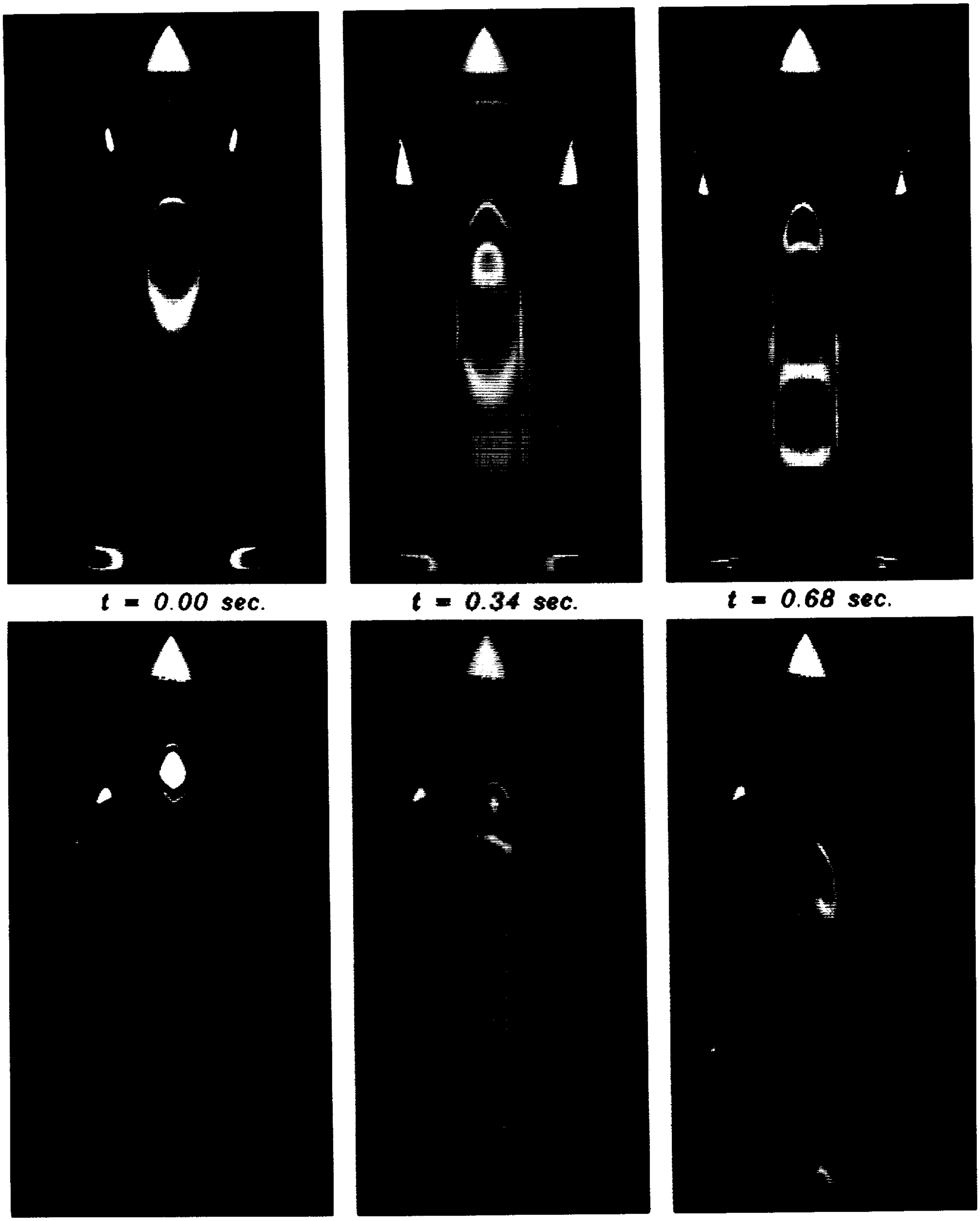
R. Meakin, P. Buning

The need to carry out computational fluid dynamics (CFD) simulations of a Space Shuttle abort mode known as "fast sep," which calls for the Shuttle Orbiter to separate from the rest of the launch vehicle during its ascent, has motivated a research effort over the past 2 years. Based on the chimera overlapped-grid domain decomposition approach, a method for unsteady dynamic grid applications has been developed. The method is general and is intended for time-accurate simulation of three-dimensional multiple-body viscous flows given arbitrary grid combinations, body shapes, and relative motion between grid systems. The method has been applied to a range of test problems, including generic bodies in relative motion, store separation, and the Shuttle solid rocket booster (SRB) separation sequence.

The method is composed of three major functions: the flow solver, body movement, and grid connectivity. The F3D flow solver uses a finite difference approximation to the thin-layer Navier-Stokes equations, with the algebraic Baldwin-Lomax turbulence model. Flux splitting is used in the streamwise direction to accelerate convergence in supersonic applications. In the application highlighted here, the trajectory of the SRB was prescribed, rather than being computed from aerodynamic forces. Grid connectivity information is supplied by a modified version of the PEGASUS code developed at the U.S. Air Force Arnold Engineering Development Center. PEGASUS establishes all of the linkages between grids that are needed by the flow solver. These include determining interpolation coefficients, and setting up logic for grids making holes in overlapping grids.

For moving grid applications, modifications to PEGASUS involved using knowledge of previous holes and grid connections to aid in locating these features at following time steps. Thus, as neighboring bodies move, grid interconnections can be generated more rapidly.

The present demonstration case is the first 2/3 second of the SRB separation sequence. This



Time-accurate simulation of the Space Shuttle solid rocket booster separation sequence takes place at an altitude of 50,000 meters, just over 2 minutes into the Shuttle flight. Airspeed is about 4.5 times the speed of sound.

In the figure, pressure loads on the surface of the Shuttle are shown at three times: before separation, and at 1/3 second and 2/3 second after SRB separation. Again, in this case the SRB motion was prescribed. In the top views, the Shuttle Orbiter is drawn as semitransparent, to allow viewing of the pressures on the surface of the external tank. In the side views, the SRBs are similarly drawn. Changes in high- and low-pressure patterns, caused by shock waves and the close proximity of the SRBs, external tank, and Orbiter can be seen.

As a precursor to this calculation, steady flow numerical results were obtained and compared with flight and wind tunnel measurements for a wide range of flow conditions. Agreement was very good, providing a significant degree of computer code validation. The difficulty in obtaining experimental measurements for this high-altitude, high-speed unsteady process further magnifies the importance of this CFD simulation.

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Three-Dimensional Structure of Plane Mixing Layers

R. Mehta, J. Bell

During 1989, a program objective of the Ames Research Center's Fluid Dynamics Research Branch was to improve the basic understanding of turbulent mixing layers through detailed experiments emphasizing overall control of the structure and mixing in this important free-shear flow. The experiments also document inflow boundary conditions and create a data base for comparison with full Navier-Stokes numerical simulations.

The present study was designed to establish *quantitatively* the presence and role of the secondary vortex structure (in the form of streamwise vortices) in the development of a plane turbulent mixing layer at relatively high Reynolds numbers. A two-stream mixing layer with a velocity ratio of 0.6 was generated with the initial boundary layers laminar in a new wind tunnel specifically designed for mixing-layer research. The streamwise vorticity in a plane mixing layer was measured directly for the first time using a rotatable cross-wire probe.

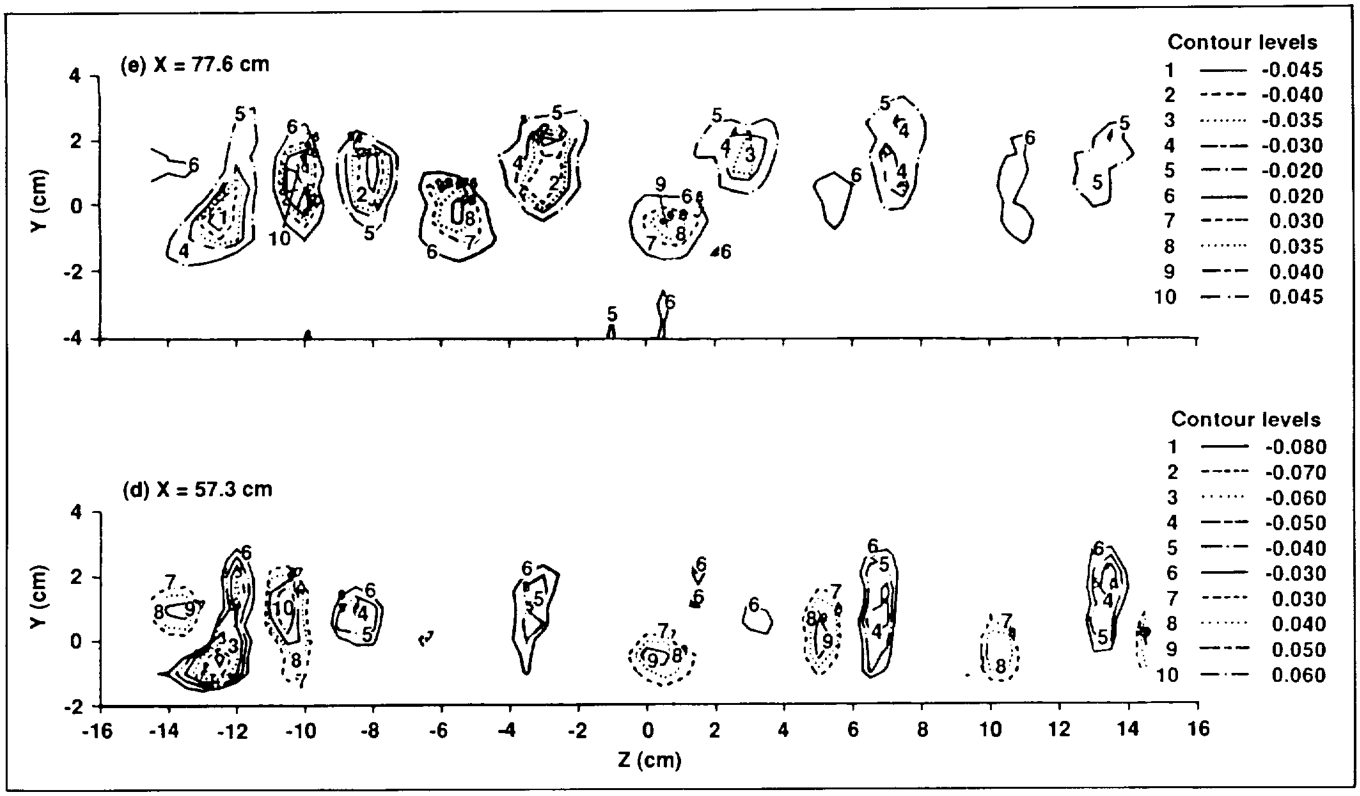
Experimental data revealed important details regarding the origin, reorganization, and decay of the streamwise vortices. Initially, the streamwise vortices are found to appear just downstream of the first spanwise roll-up, in clusters containing vorticity of both signs.

Farther downstream, the vortices reorganize to form counter-rotating pairs, as shown in the first figure. The spacing of the streamwise vortices increases, scaling with the mixing-layer vorticity thickness, while their strength decays as approximately $1/X^{1.5}$. In the near-field, the streamwise vortices grossly distort the mean velocity and turbulence distributions within the mixing layer.

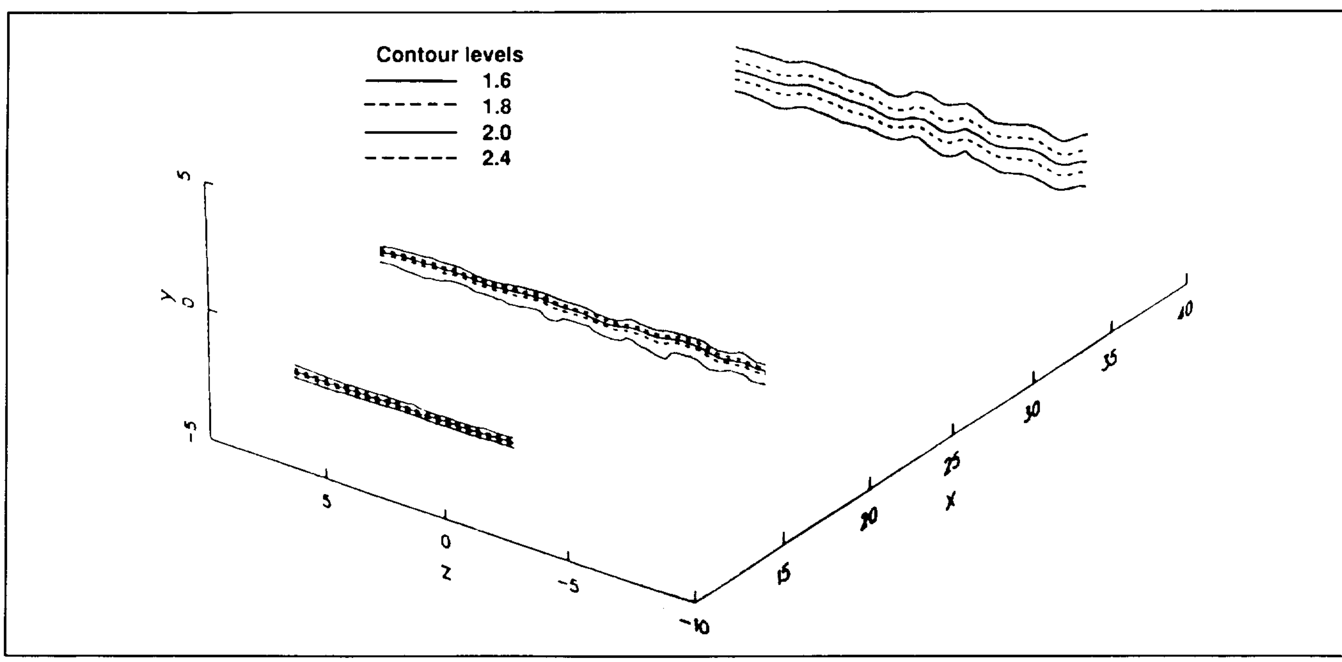
The second figure shows how the mean streamwise velocity contours are distorted by the presence of the vorticity—the wavelength of the distortion was found to increase with downstream distance, while the amplitude decreased. One of the main findings of the present study was that the streamwise vorticity is strongly correlated in position, strength, and scale with the secondary shear stress ($\overline{u'w'}$).

The contours for $\overline{u'w'}$ (see the third figure) show an organized array of vortical structures in counter-rotating pairs. The secondary shear stress data suggest that the streamwise structures persist through to the self-similar region, although they are very weak by this point and the mixing layer otherwise appears to be nominally two-dimensional.

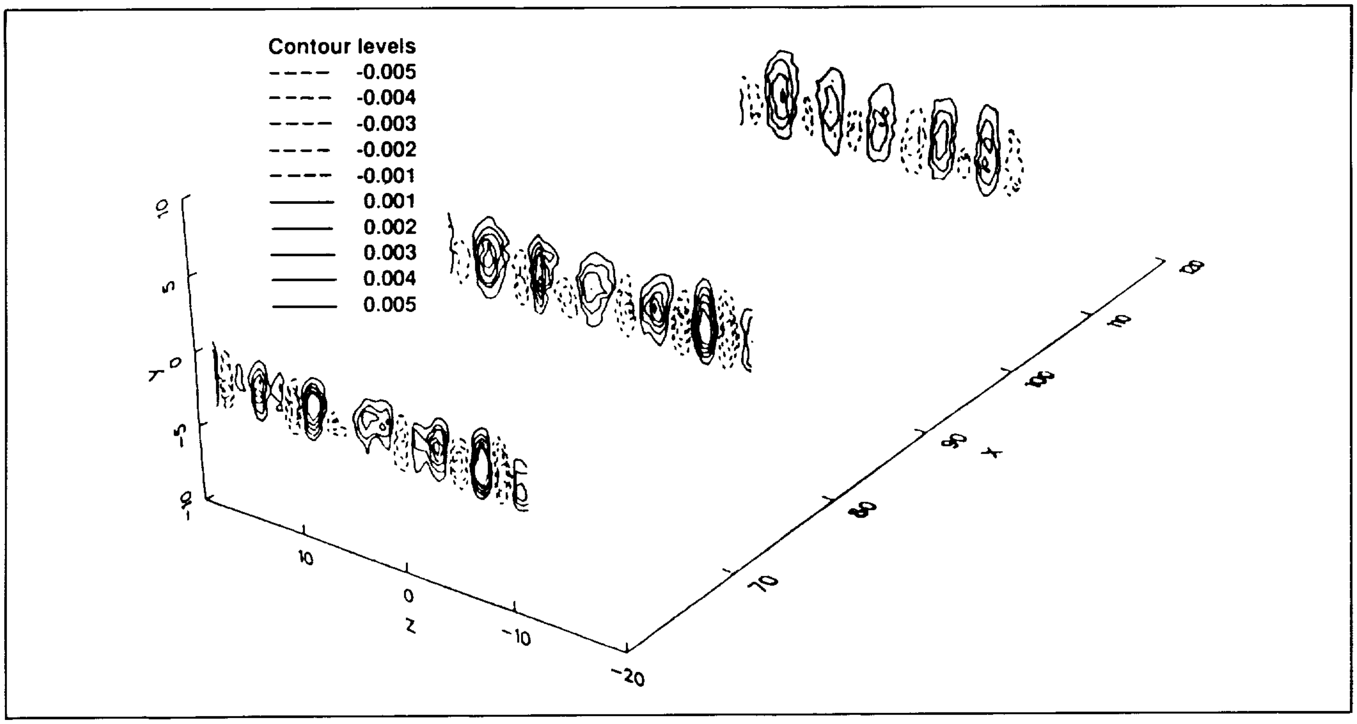
These direct measurements of the streamwise vorticity are being used to investigate ways of controlling the structure and mixing properties of plane mixing layers.



Mean streamwise vorticity (ω_x/U_0, cm^{-1}) contours



Mean streamwise velocity (U/U_0) contours



Secondary shear stress ($\overline{u'w'}/U_0^2$) contours

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Unstructured Grids In Computational Fluid Dynamics

M. Merriam, T. Barth

The first step in any computational fluid dynamics (CFD) effort is the generation of a suitable grid. Generating structured (topologically rectangular) grids around complicated geometries such as multi-element airfoils is not easy—in some cases it is the most difficult part of the job.

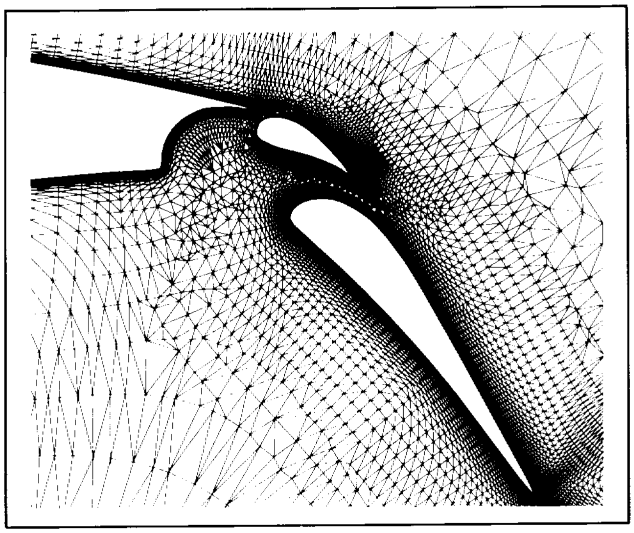
Generating unstructured grids for complicated geometries is much easier. A three-step process is used. First, existing techniques for structured grids are used to generate a suitable distribution of grid points around each airfoil element without connecting these points in any way. Second, a Delaunay triangulation of these points is performed to yield a triangular mesh. Finally, a CFD solution is obtained by using the triangular mesh.

An example of the triangulation is shown in the first figure. This kind of mesh generation is very robust and insensitive to the geometry or the location of each gridpoint. It is also fast—a two-dimensional grid such as this one can be generated in less than a minute using a workstation.

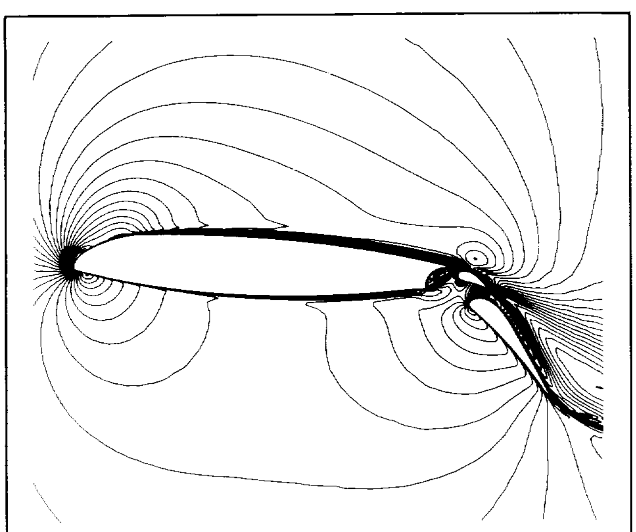
Flow solutions using this type of mesh agree well with solutions obtained using structured meshes. These solutions are not very sensitive to the location of gridpoints—random distributions have been tried successfully.

The mesh shown in the first figure was used to generate the flow solution shown in the second figure.

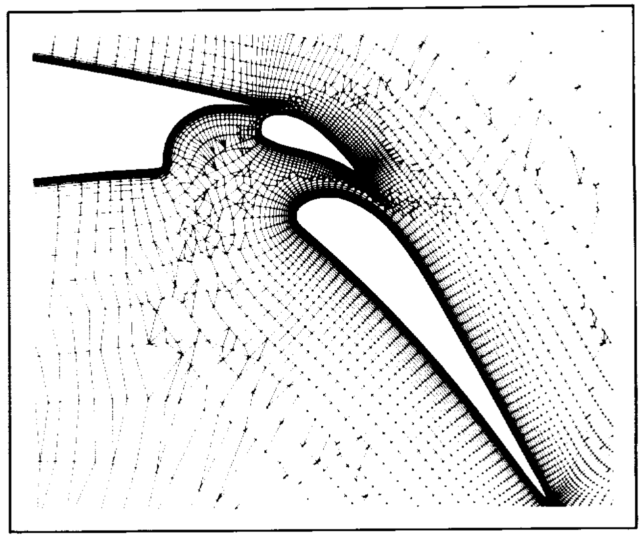
Essentially identical results can be obtained at significantly lower cost by the selective removal of some edges. This process, applied to the triangular grid shown in the first figure, yields the hybrid grid of triangles and quadrilaterals shown in the third figure. In this case the solution accuracy is unaffected, yet the cost is reduced by about one-third.



Delaunay triangulation for a multi-element airfoil



Mach contours for three-element airfoil –2° angle of attack, Mach 0.30, and Reynolds number of 4.7 million; Baldwin-Lomax turbulence model



A hybrid grid with both triangles and quadrilaterals

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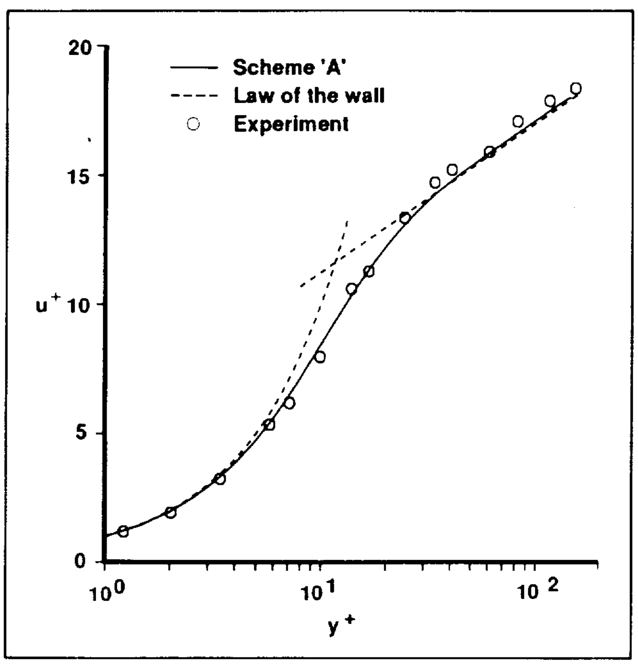
Direct Simulations of Turbulent Flow Using Finite-Difference Schemes

M. Rai, P. Moin

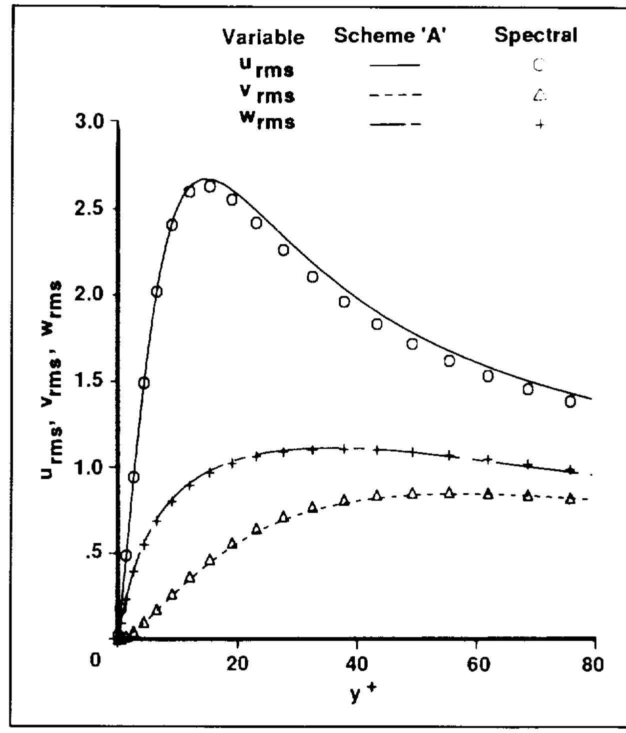
To date, the most successful direct simulations of turbulent flow have been performed with spectral methods because of the very high accuracies of these methods. However, spectral methods are difficult to use for complex geometries. They are more complicated than finite-difference techniques and they are not the prevailing methods in existing application codes. An advantage of finite-difference schemes over the highly accurate spectral methods lies in the ease with which they can be applied to complex geometries. Finite-difference methods are also simple to implement and are the most commonly used methods in current application codes. The major shortcoming of currently used finite-difference methods is that their accuracy levels are inadequate.

To overcome the accuracy problem, a high-order-accurate, upwind-biased, finite-difference method was developed. This method has been used to compute incompressible, fully developed, turbulent channel flow. The upwind method was found to yield mean flow properties as well as first- and second-order statistics that agreed well with both experimental data and earlier spectral simulations.

The first figure shows the mean velocity distribution in the channel. The symbols represent experimental data and the dashed line represents the law of the wall. The finite-difference method is referred to as Scheme A in the two figures. Agreement with experimental data and the law of the wall is good. The second figure shows a comparison of the turbulence intensities obtained with the upwind finite-difference method and spectral data. All three components computed by the finite-difference method agree well with the spectral data.



Mean velocity profiles normalized by wall shear velocity; Scheme A, fine-grid



Root-mean-square velocity fluctuations normalized by the wall shear velocity. Comparison with spectral data; wall coordinates, Scheme A, fine-grid

An additional advantage of the upwind-difference scheme is that it does not require a kinetic energy conservation property to control aliasing error. The dissipative nature of the upwind scheme results in a damping of the higher frequency content. As a result, very little energy is aliased back. At present it appears that the high-order-accurate, upwind-biased method is a good candidate for direct simulations of turbulent flows associated with complex geometries.

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Development of Three-Dimensional Mixing Layers

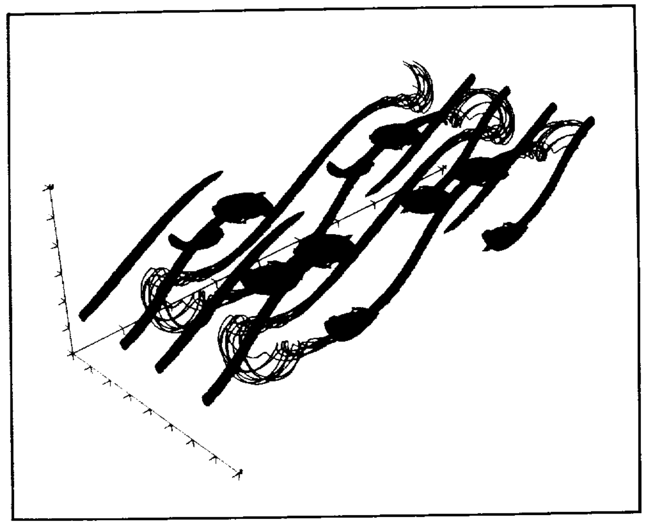
M. Rogers, R. Moser

The onset of three-dimensionality in plane mixing layers is poorly understood but is critically important in achieving efficient mixing. A numerical method has been developed to simulate time-developing free shear layers in an infinite domain to investigate the three-dimensional (3-D) instabilities and the development of 3-D structures in a plane mixing layer. A low-heat-release, fast-diffusion reaction is also simulated to address questions of mixing efficiency.

The streamwise computational domain size is chosen to be a multiple of the most unstable wavelength of the initial error function mean velocity profile. A small, two-dimensional (2-D) perturbation then leads to the development of spanwise rolls resulting from the Kelvin-Helmholtz instability. The spanwise extent of the computational domain is chosen to be a multiple of the most unstable spanwise disturbance associated with the developing spanwise rolls. Various low-wave-number, small-amplitude disturbances are used to excite the 3-D instabilities. It is found that while the flow is very sensitive to initial conditions (corresponding to inlet conditions in the spatially developing problem), a typical evolution is observed.

The 3-D structure of the vorticity field of a typical simulation is shown in the figure at a time when the energy in the fundamental 2-D mode saturates (rollup of spanwise rolls completed). The spanwise vorticity, indicated in blue, is concentrated in cup-like regions and is much stronger than that present in a 2-D simulation begun from the same 2-D disturbance. This difference is due to vortex-stretching mechanisms that are absent in 2-D flows. Lower contour levels reveal a corrugated tube of spanwise vorticity running between the cup-like structures shown in the figure.

Also shown in the figure are the rib-like streamwise vortices associated with the 3-D disturbances (in red). These vortices are responsible for the



Vorticity structure in a three-dimensional plane mixing layer

mushroom-like structures observed in many experiments and create similar mushroom-like patterns in the reactant concentrations of the simulations. Vortex lines drawn through the cores of these vortices (black lines in figure) show that these are well-defined vortex structures and not just regions of streamwise vorticity. The figure also indicates that the vortex lines associated with the rib-like structures remain distinct from those associated with the corrugated spanwise rolls.

Simulations that include pairing of the (corrugated) spanwise rolls and even a second pairing of these resulting paired structures have also been performed. Some of these simulations undergo a transition from the large-scale, well-defined structures shown in the figure to much more complicated small-scale vortical structures. It is believed that this simulated transition is associated with the experimentally observed "mixing transition" which leads to small scales and increased mixing efficiency.

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Three-Dimensional Elliptic Grid Generation

R. Sorenson

Computational fluid dynamics (CFD) is a valuable technical tool in the design of airplanes, rockets, submarines, automobiles, jet engines, and in a wide variety of other applications. Great savings in cost and time are frequently cited, and CFD can in some cases be used to gain insights which cannot be obtained in any other way.

But the usefulness of CFD is limited by the ability to do computer modeling of geometrically complex shapes. That problem can be subdivided into (first) describing to the computer the object in which there is interest, and (second) generating a computational grid about or within that object. A computational grid is a collection of many (typically tens of thousands, hundreds of thousands, or even millions) points at which the computer will find numerical data describing the flow. These numerical data give the designer insight to refine the object's design.

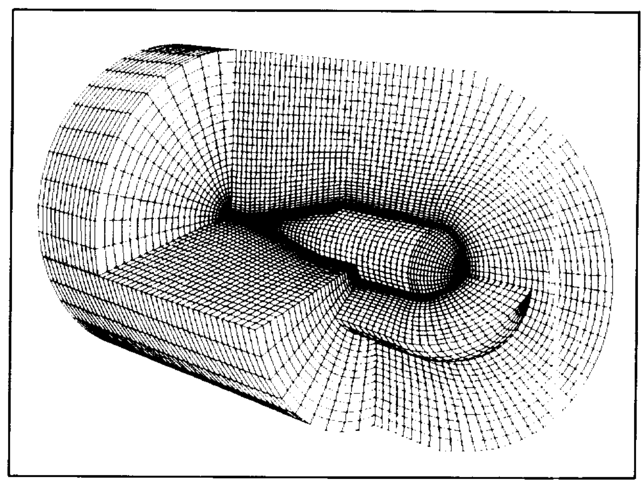
Placement of those grid points is a matter of some concern. They must be located close enough together to resolve rapid changes in the flow where such resolution is required, but they must be sparse enough in other regions so that the total number of points is manageable. These and other considerations make the problem of grid generation a formidable one. A "good" grid reduces computer time, reduces human labor time, and increases accuracy. A "bad" grid has the opposite effects.

Grid generation is performed by computer programs. A new grid-generation program, called 3DGRAPE (standing for three-dimensional grids about anything by Poisson's equation), has been developed by the Advanced Simulation and Analysis Project Group in the Applied Computational Fluids Branch at Ames Research Center. The program makes three-dimensional (3-D) grids, allowing examination of real 3-D objects, rather than being limited to simplified two-dimensional "slices" through them. It generates grids by solving equations from a class of equations said to be elliptic. This causes the grids to be very smooth, a highly desirable feature. The grid-generation equations also allow the user to specify distances between successive grid points in the direction perpendicular to the surface of the object, a requirement of any grid-generation method. The regions surrounding or inside of geometrically complex objects must frequently be broken up into zones (or blocks), with each zone gridded separately. This program supports that practice, and in fact is designed to make zonal decomposition an easy and straightforward matter. Great care was taken to make this program easy to use on a wide variety of applications.

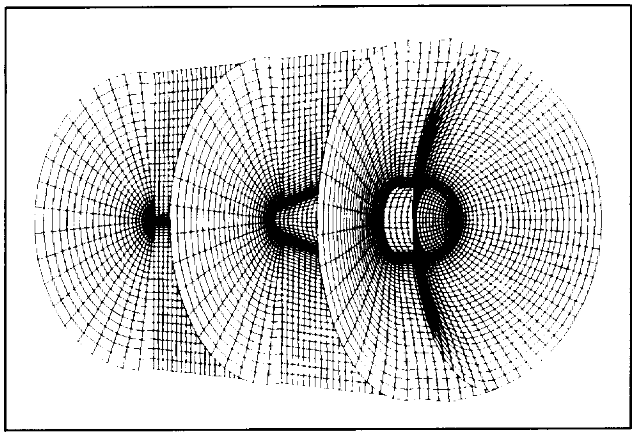
Grids consist of points, but are frequently plotted as collections of intersecting lines. Each place where lines intersect is a grid point. The figures show a grid generated by the program about an object resembling a teardrop (which might represent a helicopter's fuselage).

The first figure shows a cutaway view of the entire grid. The reader can imagine grid points packed everywhere about the object. The second figure shows some isolated grid surfaces in the same grid. Although it is not obvious from these figures, this grid was generated as three zones, and then reassembled into one grid. This grid consists of approximately 50,000 points, and required approximately 2 minutes on a CRAY supercomputer.

It is expected that this program will see wide application.



Cutaway view of grid about teardrop-shaped object



Isolated grid surfaces in grid about teardrop-shaped object

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Validating a Code and a Turbulence Model Appropriate to Circulation-Control Airfoils

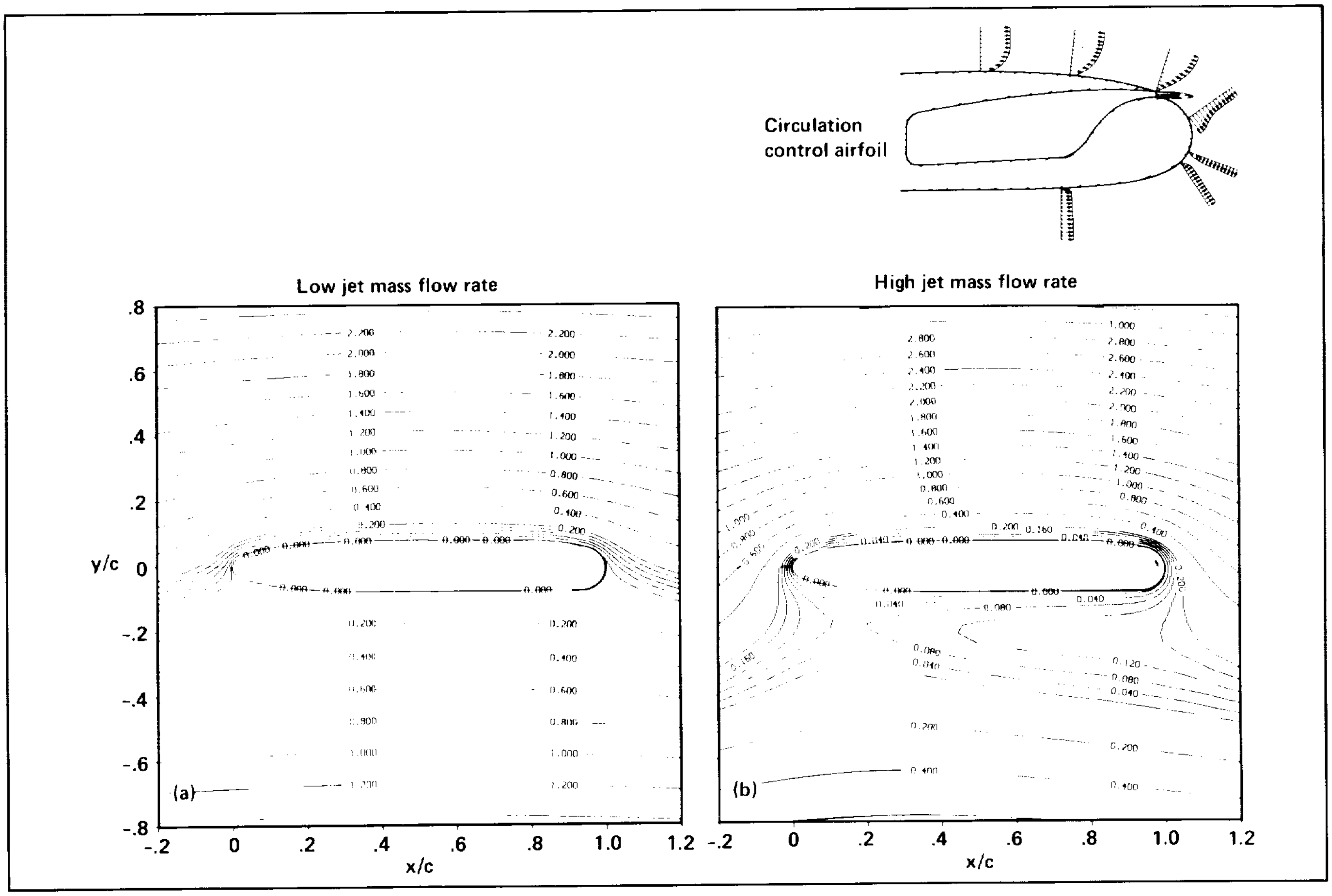
J. Viegas, M. Rubesin

An efficient computer code for calculating flow about a circulation-control airfoil within a wind tunnel test section has been developed. It is being validated for low-subsonic, two-dimensional flows for which extensive data exist.

Two basic turbulence models and variants thereof have been successfully introduced into the algorithm, the Baldwin-Lomax algebraic, and the Jones-Launder two-equation models of turbulence. The variants include adding a history of the jet development for the algebraic model and adding streamwise curvature effects for both models. Difficulties in the validation process have been identified. Turbulence model and code improvements to proceed with the validation process have also been identified.

Typical calculations showing the effect of the mass flow rate of the wall jet on the flow pattern about an airfoil at zero angle of attack and at a Mach number of 0.1 are shown in the figure. The higher jet mass flow rate (by a factor of three in this instance) caused stagnation points to coalesce and leave the lower surface as shown, and it more than doubled the effective lift.

This computer code represents a new and useful tool for evaluating appropriate turbulence models for use in designing improved circulation control airfoils. It is being applied to a new Ames Research Center transonic circulation-control airfoil experiment, at a Mach number of 0.7, to predict the gross flow features with the Jones-Launder two-equation turbulence model in advance of the performance of the experiment. In this instance the code may eliminate



Comparison of the effect of jet mass momentum on the streamlines about a circulation control airfoil, Baldwin-Lomax turbulence model

some surprises, in addition to being used subsequently in the development of improved turbulence models for this application.

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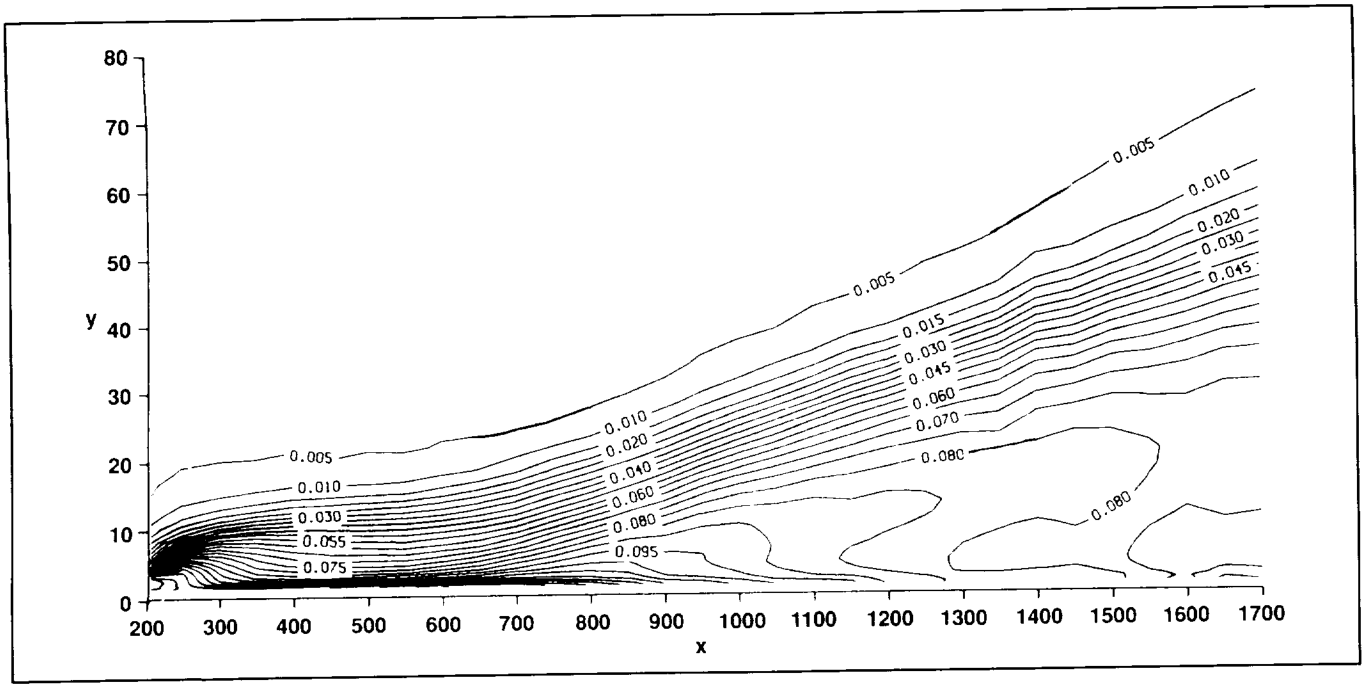
Total Automation of a Computer-Controlled Experiment for Full Navier-Stokes Code Validation

J. Watmuff

The main objective is to obtain highly accurate mean-flow and turbulence measurements in a low Re_q turbulent boundary-layer subject to an adverse pressure gradient (APG). This flow will provide a challenging test case for computational fluid dynamics (CFD) validation as well as a useful contribution to the research literature.

A trip-wire is used for transition. A short region of zero pressure gradient is maintained after the trip before application of a favorable pressure gradient (FPG). The FPG establishes a self-preserving layer which is a suitable initial condition for CFD simulation and which also helps minimize trip effects while maintaining a low $Re_\theta \approx 600$.

Conventional pitot tube and single and dual (cross) hot-wire instrumentation is used. A sophisticated high-speed, computer-controlled, three-dimensional (3-D) probe traverse has been integrated into the Fluid Mechanics Laboratory (FML) Boundary Layer Wind Tunnel. Total automated computer control of tunnel speed, probe traversal, and data acquisition allows long-duration experiments to be performed continuously over several days without manual intervention.



Contours of $\overline{u^2}/U_0$ (reference velocity $U_0 \approx 6.5$ meters/second) in a plane normal to the wall along the centerline of the tunnel

This mode of operation required several significant new developments. For example, large and complex 3-D measurement grids can be programmed and viewed ahead of time. The high-speed capability of the traverse is used for crossed-wire calibration by oscillating the probe across a uniform stream at high speed. Hot-wire calibration drift is monitored, and new calibrations are performed (automatically) if the drift exceeds some tolerance (typically 1%). Other features that have proved vital for long-duration unattended experimental runs include (1) automatic error detection and recovery schemes, and (2) the provision of emergency asynchronous manually initiated software interrupts for hardware checkouts and for access to approximately 125 menu-settable control variables.

A high-speed 15-bit Tustin analog-to-digital converter is being used in conjunction with one of the FML microVAX II computer systems to process massive quantities of data using a newly developed double buffering scheme. Previously acquired data in one buffer are processed concurrently while the alternate buffer is being filled with new data. New algorithms provide high-speed on-line data processing; that is, 25,000 samples/second for single wires, 10,000 samples/second for crossed wires. The longest duration continuous experimental run to date consumed more than 90 hours of microVAX II CPU time over a period of 130 hours.

Closely spaced profiles are needed in the region of FPG to examine the asymptotic approach to self-similarity and in the region of APG where there is rapid growth with streamwise distance. A complete set of 37 mean velocity ($\overline{U}$) profiles and Reynolds stress ($\overline{u^2}$, $\overline{uv}$, $\overline{v^2}$, $\overline{uw}$, and $\overline{w^2}$) profiles normal to the test-plate have been measured at 50-millimeter intervals in the streamwise direction. Each profile consists of more than 30 points where up to 10^6 samples were used for the averages at each point. The high spatial density of the data allows contours of measured quantities to be produced. For example, the figure shows contours of $\overline{u^2}/U_0$ along the tunnel centerline.

Integration of total automated computer control into the experiment has allowed these spatially dense measurements to be obtained efficiently in a relatively short period of time.

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An Analytical Model of the Response of Multihole Pressure Probes

G. Zilliac

Multihole pressure probes have long been used to obtain velocity and pressure information in fluid flows. Many probe geometries have been developed, including certain probes which are highly application-specific (for example, turbomachinery, boundary layers, free shear flows, etc.). The basic principle of operation, which most multihole probes have in common, is the ability to determine velocity magnitude and direction from a measured pressure differential. The particular choice of a probe type depends on interference effects, probe access, probe volume, time response to mean pressure changes, sensitivity, and flow inclination to the probe, among others.

When a probe is being selected or designed for a specific application, because of the large number of possible configurations choices are often made based on minimal performance information, rules of thumb, and experience. An accurate, easy-to-use method of determining specific information such as probe sensitivity is desirable, especially during the probe design phase.

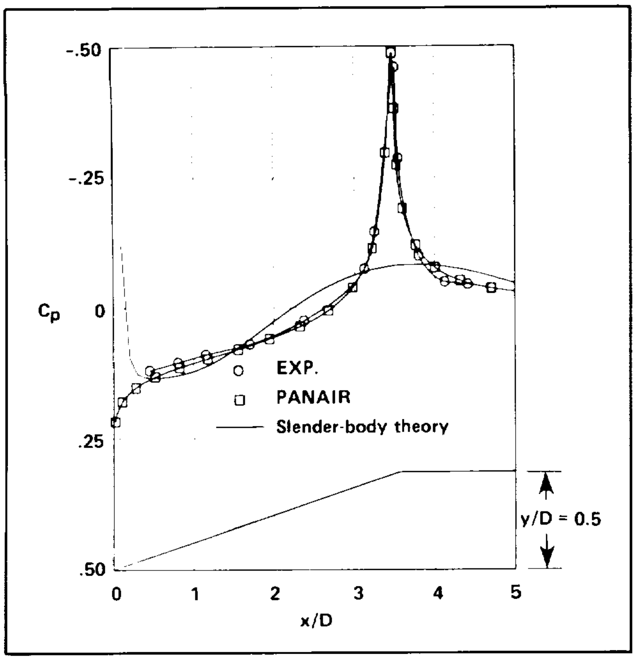
Existing analytical methods in the literature can be classified as being based on either slender-body theory or potential flow-singularity methods. The main argument in favor of the slender-body approach is that it is possible to derive explicit analytical expressions for the calibration functions. These expressions allow one to gain insight into the various scaling laws which govern probe behavior. Unfortunately, the accuracy of the slender-body technique is limited by the slender-body assumption. The main advantage of the singularity method approach is that an accurate numerical solution may be computed for complicated probe geometries. The penalty is the amount of computer time required for one solution of a typical panel method.

Both methods have been investigated in the present study and the slender-body approach was found to be too inaccurate to give much useful information to probe designers. As a result, an analytical method was developed, based on a novel use of a panel method, to give a relatively accurate prediction of probe behavior.

In the present study, the approach to modeling pressure probe behavior was to combine the aspects of slender-body theory and panel methods. The panel-method approach is preferred over the slender-body approach because of the severe limitations imposed by slender-body theory near the probe tip (tip slope must be much less than 1); on the other hand, the simplicity of slender-body theory makes it desirable from a probe optimization point of view. To avoid computing a panel-method solution for every onset flow angle, an approach using two modified, superimposed potential-flow solutions has been applied. The model is general and can be applied to most probes that are bodies of revolution.

The computer program PANAIR has been used to find the potential flow solutions required by the probe model. This panel method solves Laplace's equation for the total velocity potential by superimposing quadratically varying doublet and linearly varying source singularities on paneled portions of the boundary surface. The solution for a body at an arbitrary angle of attack and sideslip can be found by forming a linear combination of the solution at 0° and 90° angle of attack. No additional approximation is involved in this superposition and transformation of the potential flow solution. This technique should be generally applicable to any body of revolution where the potential flow solution is desired at an arbitrarily chosen flow onset angle.

An example of the inability of the slender-body theory to predict the pressure distribution near the tip of a shape which is similar to a typical pressure probe geometry is shown in the figure. This figure presents a comparison of the tip pressure variation with the x-position for a cone with a cylindrical afterbody at 0° angle of attack as predicted by a panel-method, slender-body theory, and as measured in an experiment. As can be seen, the slender-body



Cone-probe pressure distribution at 0° angle of attack

theory result is in error by a significant amount in the region where the greatest accuracy is required for probe modeling.

The pressure peak at x/D = 2.8 is captured well by PANAIR, while there is virtually no indication of this pressure peak in the slender-body results. This figure demonstrates that slender-body theory is sufficient for bodies with continuous, slowly varying shapes, but is highly inaccurate for the types of geometries which are common to multihole pressure probes. On pointed bodies, singular behavior of the slender-body equations at the tip causes substantial deviations from the actual tip pressure.

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Design Knowledge Capture and Retention

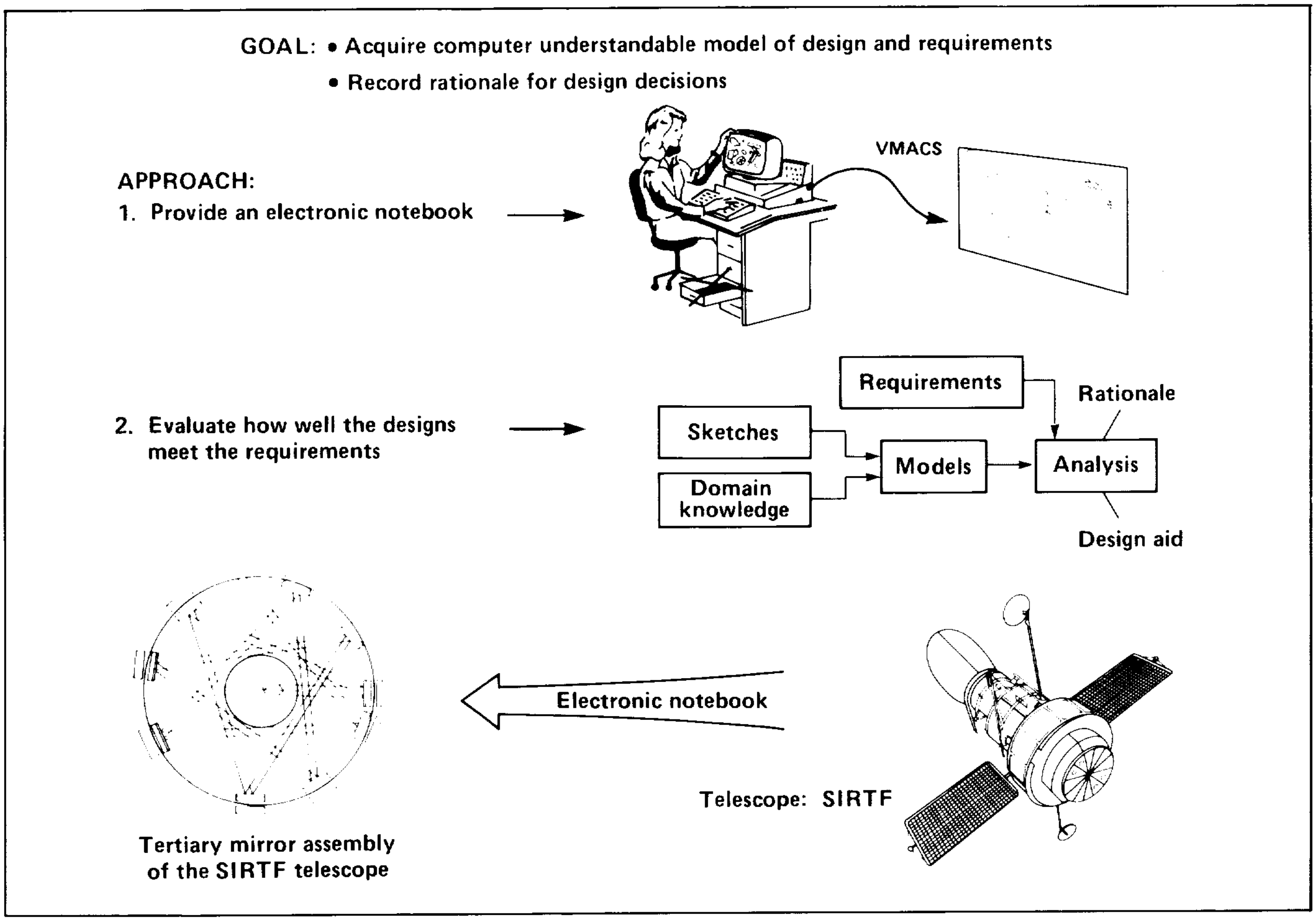
C. Baudin

NASA designs, builds, and operates some of the most complex physical devices known to man. A significant problem is the acquisition, retention, and use of lifecycle knowledge about those devices. An important starting point is the development of tools which enable knowledge capture and retention throughout the design stage.

As part of the research thrust in the design and understanding of physical systems in the artificial intelligence research program at Ames Research Center, a project has been developed with two major goals: first, to capture design rationale and make it available for later operational use and, second, to provide design tools that aid engineers throughout the design process.

The figure shows both the goals and evaluation model by which requirements and knowledge can be preserved for recovering critical design or implementation decisions. The research is being conducted by a team of computer scientists in the Ames Artificial Intelligence Research Branch, telescope design engineers in the Ames Telescope Systems Branch, and mechanical engineers at the Stanford University Center for Design Research.

In 1989, significant progress was made toward both goals. First, an electronic notebook system, VMACS (which stands for Visual EMACS; EMACS is a common text editor in the computer science research community), was developed and made available to designers of the Space Infrared Telescope Facility (SIRTF). It is being used regularly and has begun serving as an operational repository for design knowledge on portions of SIRTF. Second, a prototype knowledge-based system was developed that uses the electronic notebook to infer design rationale and compare it to design constraints.



Design knowledge capture and retention

The team-interactive nature of the work has allowed focusing of the effort into several continuing areas. For example, a need has been identified for developing notebook organization aids within VMACS. Using domain-independent heuristics, selected pages of the notebook are intended to be automatically indexed and summarized. In particular, an appropriate heuristic might be "text in boldface near the top of a page or outline is worthy of summarization." Such summary and indexing systems can aid designers in organizing and accessing work.

Second, a need has been identified to add capabilities which allow more difficult questions to be asked about why particular design decisions are made. Hence, the system has been formulated to eventually compare an originally chosen design to alternative design options where key decisions were resolved differently, and to report on the difference in design requirements and constraints which support the various decisions. The close ties to an actual device like SIRTF ensures that, while much of the effort is still in the realm of fundamental research, the tools and mechanisms being developed will be easily transferred to practical use.

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Planning and Scheduling to Achieve Goals—Intelligent Agents

M. Drummond

Future autonomous spacecraft and exploration devices will need to "understand" and "reason" about their goals, potential actions, and changes to their environment caused by their own and other agents' actions. Such systems must be able to monitor their actions and modify initial action plans accordingly. We give the name "intelligent agents" to such systems. Research on intelligent agents is a major thrust of the Ames Research Center artificial intelligence research program involving scientists of the Ames Artificial Intelligence Research Branch, Stanford University, SRI International, and Teleos Research, Inc.

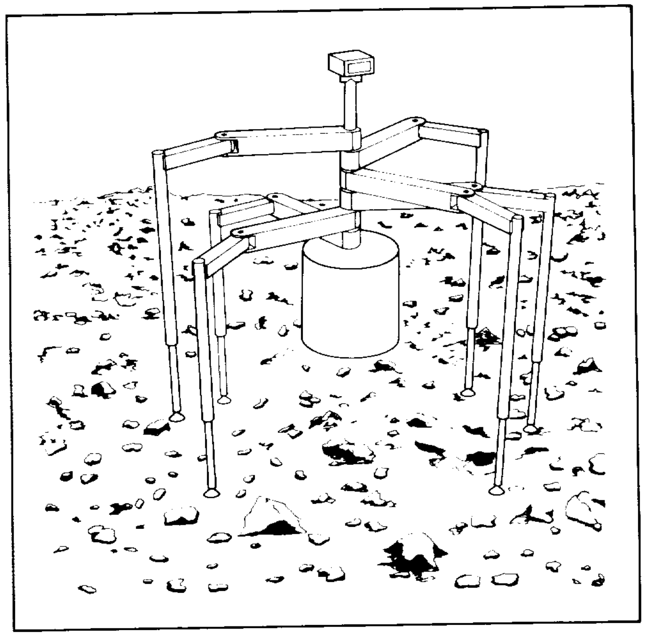
During 1989, research focused on several topics. The first is architectures that enable the development of plans, plan execution monitoring, and replanning within the agent.

One architecture, called "action networks" focuses on a formal, circuit-like representation of an active plan where input is from both ongoing goals and a set of sensors out to the external environment. This architecture has the advantage of being easily adapted into actual layouts for integrated circuits that can implement and be responsive to a significant class of robotic action goals.

A second architecture, called "situated control rules," concentrates on practical real-time behavior by attempting to set up a mechanism for real-time planning when possible, but relying on default behaviors already stored in a "plan-net" when time is not available for further planning.

Both architectures are being evaluated on simple problems within mobile robot testbeds at SRI and at Teleos, and they are envisioned as potential models for autonomous planetary rovers as displayed in the figure.

A second research topic has focused on developing mechanisms for cooperation and communication among several agents working together on a common task. A framework called "Beliefs, Desires, and Intents" is being used to allow individual agents to model expected actions by other agents in their environment. An architecture called the "negotiation model" has been developed to allow for tradeoffs between local and global goals to take place dynamically during cooperative plan execution. This is also being tested on simple mobile robot problems.



Autonomous planetary rover

Extensions of this work require developing and evaluating the architectures for planning and cooperation, moving to more realistic NASA test problems in such areas as in-space and planetary base construction and further work on planetary rovers. In addition, a new research topic is starting, which integrates learning as a powerful tool for intelligent agent performance improvement.

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Large-Scale, Multiuse Knowledge Bases

P. Friedland

The objective of this work is to develop the methodologies for constructing very large knowledge bases capable of supporting a variety of reasoning tasks related to engineered devices built by NASA.

The project is being conducted as a research collaboration involving computer scientists of the Ames Research Center Artificial Intelligence Research Branch and the Knowledge Systems Laboratory at Stanford University. These researchers are working with Hubble Space Telescope (HST) design engineers at George C. Marshall Space Flight Center and Lockheed Missiles & Space Co., Sunnyvale. A large, frame-based knowledge base containing engineering information about many subsystems of HST is being built and then automatically converted into specialized expert systems for diagnosis and redesign.

HST is an excellent domain for this research for two major reasons: (1) its subsystem complexity is typical of large NASA devices, and (2) the engineering expertise used for design, construction, and testing of HST is still resident within NASA and its contractors. A typical first-generation expert system for solving a problem related to HST (specifically, diagnosis of reaction wheel problems) is built by representing experiential, heuristic knowledge in the form of rules specific to that problem. In this project, a "deep" general-purpose structure/function model of HST is constructed along with special-purpose "knowledge compilers" able to automatically produce specific problem-solvers.

Three research topics are being explored: knowledge representation (how to efficiently store the general HST model), knowledge transformation (how to compile the general model into the specific problem-solvers), and reasoning about device behavior (how to do high-level reasoning directly on the general-purpose HST model).

The complexity of major NASA devices like HST requires the construction of knowledge bases several orders of magnitude beyond the current state of the art. The typical methodology of representing problem-specific heuristics in a first-generation expert system is an enormously inefficient way to produce the range of knowledge-based systems needed throughout the life cycle of such devices.

This work cuts to the heart of the efficiency and generality question by building a single, very large and comprehensive device model, then automatically deducing the heuristics necessary for individual specific problem-solving tasks. The detailed structure and functionality of the reaction wheel assembly of HST has been represented in a knowledge base using the frame-based Hyperclass tool. In addition, two specific knowledge compilers, one for diagnosis and one for redesign, have been built and have successfully shown the ability to convert the general-purpose knowledge base into efficient problem-specific expert systems.

These results have guided plans for continuing the research on three major paths: expanding the knowledge base to include other HST subsystems such as the power system, adding more domain-specific knowledge compilers, and determining when reasoning can occur using the general-purpose HST model directly.

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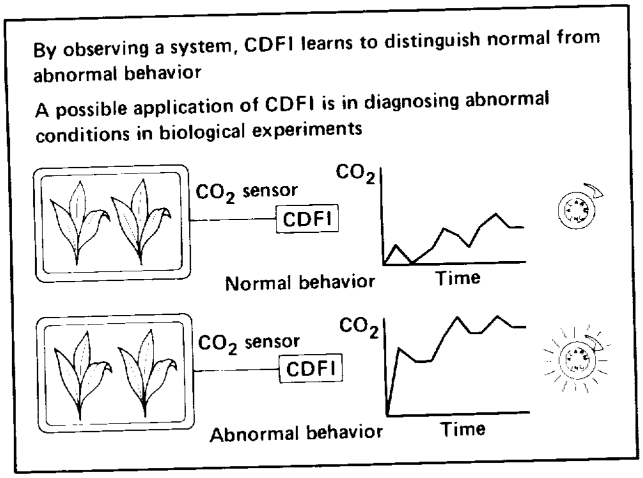
Data Prediction and Analysis

P. Laird

A major problem in the analysis of natural and artificial data is the prediction of future information based upon prior streams of data. This is relevant both to man-made systems like STS main engines (for example, assessing when a seemingly normal data stream is showing a trend toward an anomaly) as well as to natural systems like biological experiments (for example, testing whether results fall outside the current model of plant growth in microgravity).

As part of the research thrust in data analysis and theory formation in the artificial intelligence research program at Ames Research Center, research in machine learning has led to a new algorithm called cumulative distribution function inversion (CDFI) which promises to significantly advance the state of the art in such data prediction problems.

During 1989, theoretical analysis and initial implementation of the CDFI algorithm were accomplished. The algorithm learns to recognize normal conditions in a system by observing the measurements that define the state of the system and making a statistical model of that state. It does not require any a priori knowledge of the system to be specified, and it is therefore generalizable to learning about



Cumulative distribution function inversion learning

many physical systems. The algorithm works by developing a set of attribute-value vectors and deriving probabilities for the values that can be used later for predicting future data. In addition, accuracy and confidence measurements are automatically built up during the learning phase of the algorithm. These are used to reduce the size of the search space during prediction, thus improving problem-solving efficiency.

The figure displays some of the concepts involved whereby the algorithm is able to recognize variations against expected data based on its internal model of learned attribute-values.

Development of the CDFI algorithm is currently focusing on two areas. First, at least one NASA application is being selected, with system monitoring and fault detection being the most likely candidate. Initial analysis has indicated that the Crop Growth Research Facility, an experiment proposed for flight on Space Station Freedom, will be a productive domain. Second, the algorithm is being extended to handle time-dependent data wherein ordering is important.

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Photonic Processing

M. Reid, J. Downie, E. Ochoa

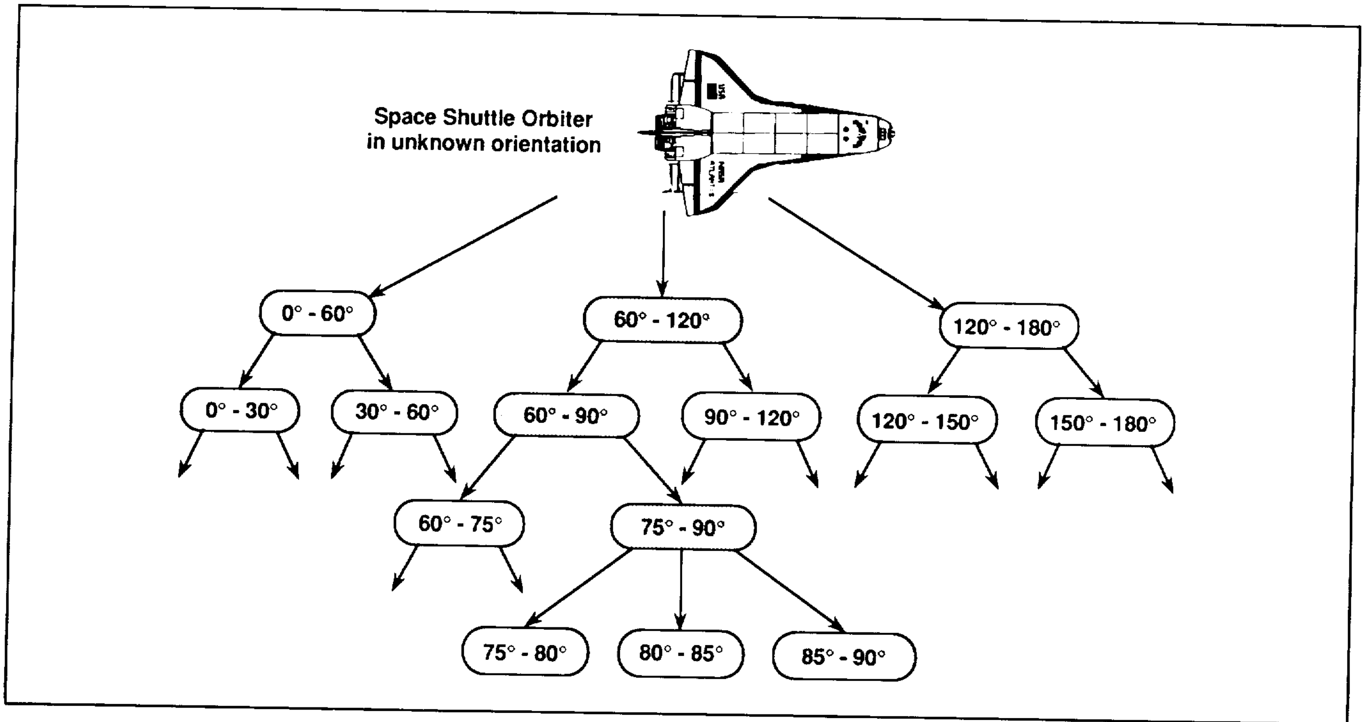
The Photonic Processing group is performing applied research on optical processors in support of the Ames Research Center's goal to lead the development of autonomous intelligent systems. Optical processors, in conjunction with numeric and symbolic processors, are needed to provide the powerful processing capability that is required for many future agency missions.

Significant strides were made in 1989 toward developing a real-time image and data analysis system. In optical image processing involving the use of optical correlators, matrix feature extraction operations are performed in parallel in the optical domain. As the input waveform does not need to be measured as a matrix of discrete values, optical processors have the potential for much higher throughput than conventional digital techniques. Real-time (video rate) performance requires that the optical filters in a correlator be rapidly updated. This is possible with some commercially available spatial light modulators, but these are binary devices which do not allow encoding of a fully complex-valued filter.

It was experimentally demonstrated that the first updatable binary filter is able to recognize an object over a range of aspect angles. Specifically, recognition of an object has been demonstrated even when the object is rotated either in- or out-of-plane by angles up to 75°.

Development of these new binary optical filters at Ames has allowed another major step to be taken toward integrating an optical processor into a larger, knowledge-based system. A library of optical filters arranged in a hierarchical data base has been developed that allows an expert system to use the optical correlator to both recognize an object (in these tests, a Shuttle Orbiter) and subsequently determine its specific orientation.

As shown in the figure, the highest level of the data base contains filters which recognize the shuttle over a wide range of views. (This type of filter is invariant to 180° rotations, therefore the 180°



Data base of optical filters designed to determine the angular orientation of a Shuttle Orbiter to within a 5° range. As the filters are invariant to 180° rotations, the data base shown covers the full 360° range of possible inputs

range covered in the highest level of the data base encompasses every possible input angle up to 360°.) At each lower level, the filters become more selective, responding to a narrower range of aspect angles. At the lowest level, the Shuttle's orientation is defined to within a 5° range. In laboratory experiments, an expert controller has used this data base of filters to determine the orientation of the Shuttle regardless of the angle at which a test input is shown.

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Knowledge-Based Scheduling

M. Zweben

Complex scheduling and resource allocation problems are prevalent throughout NASA. A typical problem is one in which a large number of tasks must be assigned start and end times, subject to time and physical resource constraints.

Two major difficulties arise in the complex scheduling problems typical to NASA missions. The first is the sheer combinatoric difficulty caused by enormous numbers of tasks combined with extremely inflexible time and resource constraints. The second is the need to be reactive to unexpected changes that occur in real NASA space missions. Therefore, this work, conducted as part of the artificial intelligence research program at Ames Research Center, focuses on both the huge search space and the need for dynamic rescheduling routinely encountered in practical scheduling.

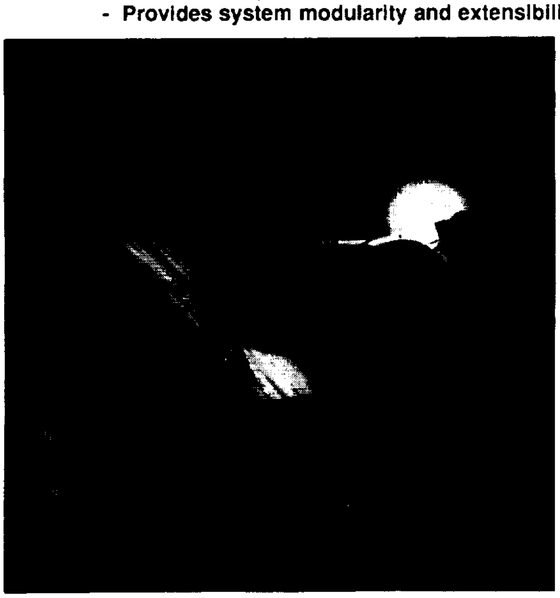
The fundamental approach being used is known as constraint-based scheduling. This involves the formal representation of all the independent and dependent variables that govern time and physical resource allocation. Once these constraints are fully "understood" by a computational system, various search methods such as backtracking, simulated annealing, and neural approaches can be used to attempt to combat the combinatoric explosion of algorithmic methods. In addition, later changes in constraints can be understood within the global context of all system constraints to enable schedule changes to be made without a complete re-evaluation of the total search space.

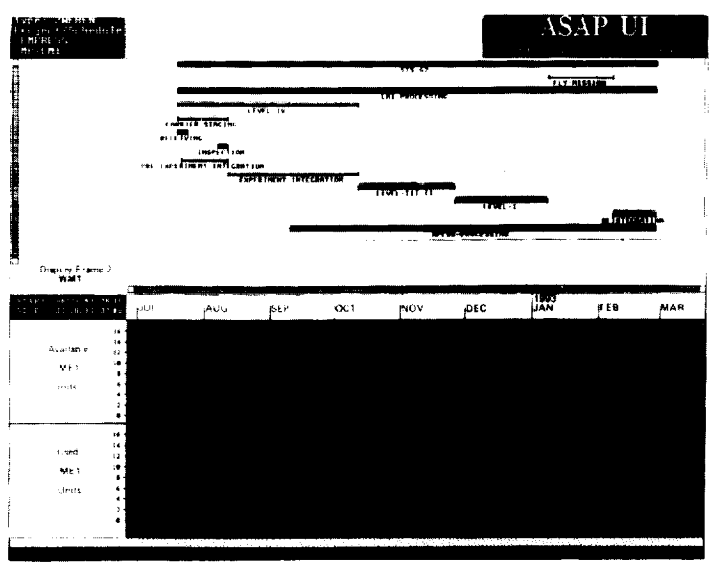
During 1989, research in this field has been supported at Ames, at Carniegie-Mellon University (CMU), and at the Space Telescope Science (STS) Institute at Johns Hopkins University. The domains of STS payload processing and Hubble Space Telescope science mission scheduling have served as fruitful testbeds for the work. At Ames, a new scheduling system which uses delayed evaluation of all data structures has been built and tested. In this method, most computational work is postponed until it is actually needed during search. Besides the improvement in search efficiency, it also allows for the representation of infinitely large data structures.

The figure shows the results of a scheduling run as applied to ground operations management of Shuttle payload processing. Actual STS-62 processing needs have been successfully addressed in this example, and an appropriate time line has been developed for use at John F. Kennedy Space Center. At CMU, the ISIS/OPIS program work in factory job-shop scheduling has been adapted to Hubble Space Telescope (HST) science scheduling. Experiments at the Space Telescope Science Institute have been conducted using neural search and

KNOWLEDGE-BASED SCHEDULING AND RESOURCE ALLOCATION

- Automatic scheduling
  - The placement of tasks in time given complex resource requirements subject to domain constraints
- Reactive rescheduling
  - Meeting the exigencies of developments during the course of the schedule
- Constraint-based representation
  - Provides system modularity and extensibility





Knowledge-based scheduling and resource allocation evaluation techniques on a network of formal constraints and suitability functions. The system developed is responsible for all long-range scheduling for HST projects.

Lessons learned in each of these projects have prompted several approaches to knowledge-based scheduling. The focus is on empirical testing and comparing the various methods and on better management of temporal relations among complex variables. In addition, a new effort is beginning on multi-agent scheduling, the coordination of many agents scheduling tasks and allocating resources concurrently.

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Discrete Particle Simulation of Compressible Flow

D. Baganoff, J. McDonald, W. Feiereisen

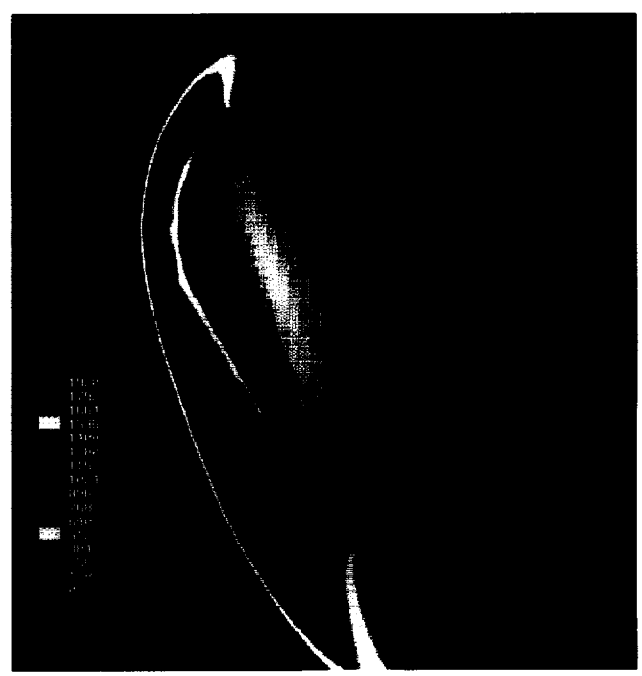
Future aerospace vehicles such as aeroassisted orbital transfer vehicles will fly at times under rarified atmospheric conditions that lie outside the regime of applicability of continuum methods. Discrete particle simulations offer the possibility of calculating within this regime. Established methods of this class, such as direct simulation Monte-Carlo (DSMC), are computationally intensive, which limits their usefulness even on current computers. The new method developed here is about two orders of magnitude more efficient, allowing the simulation of realistic three-dimensional geometries.

The focus of this work was to develop the capabilities of the model to represent the physical processes inherent in this flight regime. At the same time the algorithm has been optimized for the various machine architectures used. Although a supercomputer such as the Cray-2 greatly augments the problem-solving capacity of the method with its large memory and speed, it is not viewed as the definitive architecture for this type of simulation. Careful consideration has been given to what would constitute an ultimate machine organization for this category of scientific problem. It is evident that a computer architecture conforming to this algorithm could be far less complex and costly than a general-purpose supercomputer.

Traditional DSMC methods model the flow as a large collection of discrete particles that interact with each other through mutual collisions. The physics of collisions are modeled in detail and the overall characteristics of the flow field are extracted from the statistical properties of many collisions. These methods show great promise, but they are computationally extremely intensive. They are difficult and, even with current machines, impractical for technically interesting geometries. Restructuring of the algorithm, however, has allowed significant reductions in computational time and has brought realistic, rarified three-dimensional flows with chemical effects within reach on current machines.

The algorithm may be divided into two parts, particle motion and collisions. The representation of particle motion is the same for all particle methods including DSMC. All particles move with their own constant velocity during a timestep. After the new positions are integrated, boundary conditions are enforced and, then, the particles are collided.

The present algorithm differs significantly from DSMC methods in the collision algorithm. Simplified physical models are used to represent the interaction



Normalized pressure

between particles during collisions. Although the exact trajectories and interactions between particles are calculated in DSMC methods, the approach here is to restrict the possible outcomes of a collision to a small, previously enumerated subset of all possible outcomes and to choose from these outcomes on a quasi-random basis with a minimum of calculation. The allowable set of outcomes is defined by the usual conservation of mass, momentum, and energy.

The outcomes of DSMC collisions may be thought of as an infinite set whereas the current algorithm has discretized this "space." The more complex particle models that are now under investigation allow the nonequilibrium partition of energy among translational, rotational, and vibrational states.

Three-dimensional calculations have been performed about the aeroassisted flight experiment (AFE) geometry with 10^7 particles and 4.3×10^5 mesh cells that have produced good statistics while using less than 5 hours of Cray-2 single processor CPU time. This is more than two orders of magnitude more efficient than traditional DSMC methods.

The algorithm is extensively vectorized and has been used to study the suitability and adaptability of particle algorithms to vector architectures. The Cray-2, with its large main memory, is essential for this type of simulation as well as for providing a testbed for the computer architectural aspects mentioned above. In this light, some portions of the algorithm were hand-coded in Cray assembler language to take advantage of hardware characteristics.

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Optical Diagnostics for the Hypersonic Shock Tunnel

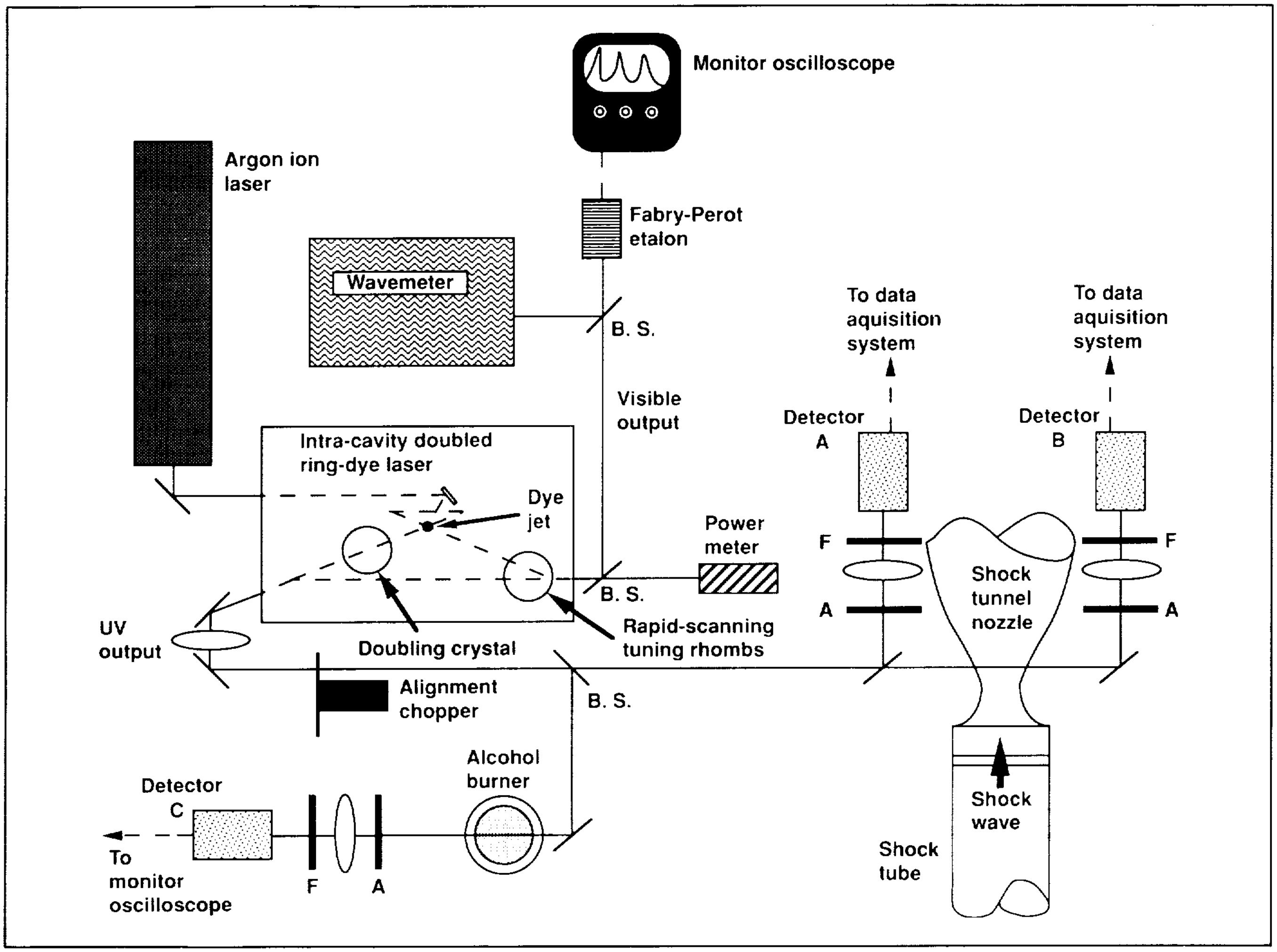
J. Cavolowsky

Development of viable, laser-based diagnostics for measuring thermochemical nonequilibrium effects in the shock tunnel at the Hypersonic Free-Flight Aerodynamic Facility is a key step toward establishing an experimental, generic hypersonics program at Ames Research Center. A primary objective is to use these diagnostics, in their early stages of development, to measure the viable test time of the shock tunnel. This is done by detecting the arrival of the OH radical found at the contact surface of the combustion-driven shock tunnel flow.

This diagnostic development effort is important because the ability to measure OH is critical to understanding nozzle flow and scramjet combustion conditions. Also, determination of test time is crucial for proper application of the shock tunnel. By using OH as a marker for the arrival of the contact surface, this diagnostic provides substantial improvement in the measurement accuracy of shock tunnel test time.

The nozzle flow field was probed using a laser-based absorption diagnostic for sensitive and accurate detection of OH. The two figures illustrate schematics of the optical layout of the remotely located laser system and the laser beam distribution and detection optics located at the nozzle test section.

This system has been developed and implemented with the assistance of Professor Ronald K. Hanson of the High-Temperature Gas Dynamics Laboratories at Stanford University. A continuous-wave argon ion pumped ring dye laser (Spectra-Physics Model 380C) with temperature-tuned intracavity second harmonic generation in deuterated ADA was used in the ultraviolet near 306 nanometers. Fixed-frequency OH absorption measurements were made at the $R_1(5)$ absorption line.



Remotely located argon ion pumped ring dye laser

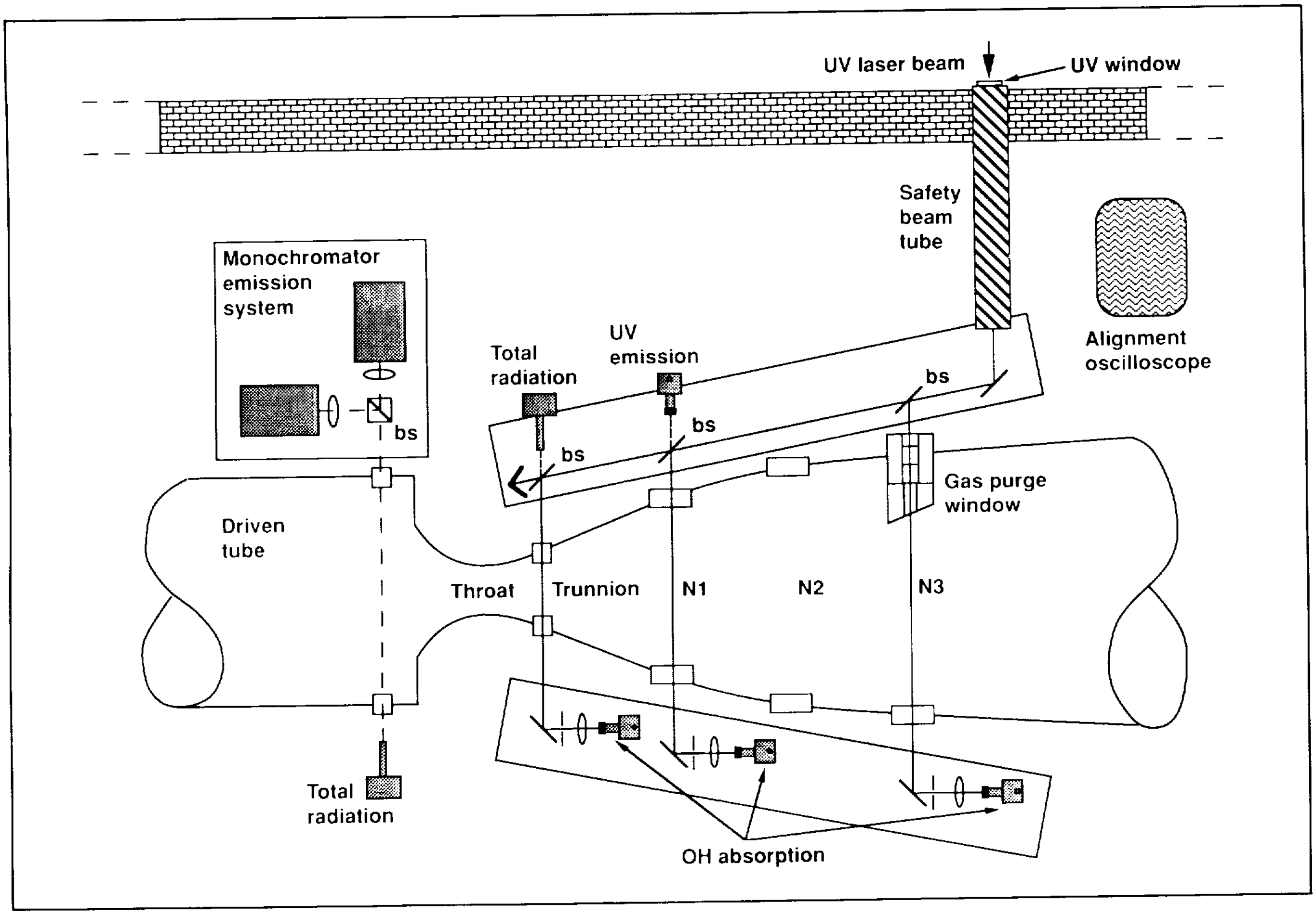
Emission of a variety of species found in the driver and driven gases was also measured in the nozzle and the reflected shock region of the driven tube using monochromators, photoresistive total radiation detectors, infrared detectors, and spectrographs.

OH was detected in the nozzle flow along with significant beam attenuation and emission distortion due to flow-field contaminants, making assignment of absolute OH concentrations difficult. It became necessary to identify and eliminate all sources of contamination before any measure of test time could be made. This was accomplished by two means. First, the laser system was tuned to a stable wavelength that was not at an OH absorption line, but was close to $R_1(5)$. This way, the contaminants would absorb the offline radiation to essentially the same degree as they would the online radiation.

Second, strong emission signatures of contaminants were identified using the emission detectors described.

With these techniques, the sources of flow contamination were systematically identified and removed. Many sources were found, but the three most significant contributors were (1) the nozzle diaphragm, (2) the concentration of oxidant in the driven gas, and (3) the high explosive used to rupture the primary diaphragm.

Aluminum, originally used as a nozzle diaphragm material, proved to be a large source of attenuating particulates and emission. It was replaced with Mylar which produced much less attenuation and emission, but did produce a measurable amount of OH from its own combustion. Replacement of air with nitrogen as the driven gas



Beam distribution and detection optics at the nozzle test section

eliminated the oxidizer and the interface combustion with the hydrogen-rich combustion products of the driver gas which created flow-field contaminants. Finally, replacing jet cord with a lance as the actuator for primary diaphragm rupture, the flow was free of significant contamination for more than 30 milliseconds after initial shock arrival.

Although the test time has not yet been reliably determined, more is now known about the shock tunnel operation parameters and their effect on nozzle flow quality than ever before was thought necessary. This information makes the Ames hypersonic shock tunnel uniquely suited for generic hypersonic research.

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Real-Gas Properties of Air and Air Plus Hydrogen Mixtures for Hypersonics Applications

R. Jaffe, D. Cooper

Members of the Computational Chemistry Branch at Ames Research Center have been engaged in ongoing hypersonics research projects to compute selected properties of high temperature gas mixtures such as those expected to be found in the shock layer surrounding the aeroassisted orbital transfer vehicle (AOTV) and in internal flows of the National Aero-Space Plane (NASP) scramjet engine. R. Jaffe and D. Cooper are coordinating this program under the sponsorship of OAST and the NASP Joint Project Office. Calculated properties include molecular photo-absorption and -emission cross sections, reaction rate constants, transport properties, and electron-impact cross sections. These basic chemical and physical data are needed as input to computational fluid dynamics calculations of the flow-field properties for these vehicles.

All of the calculations have been carried out from first principles, using state-of-the-art quantum chemistry methods. Previous studies by members of the Ames Computational Chemistry Branch have conclusively demonstrated that this approach can provide accurate reaction rate constants and cross sections for conditions of temperature and pressure that are not amenable to experimental study. The calculations involve determination of the potential energy surface (by solutions of the electronic Schrodinger equation) for the atoms and molecules involved in the spectroscopic or collisional process. Then a vibrational or scattering theory calculation is carried out using this potential energy surface to describe the motion of the constituent atoms.

During 1989, photo-absorption and -emission cross sections were determined for CN, C_2, and NO. These calculations involve determining potential energy curves and electric dipole transition moments for each molecular band system.

Reaction rate constants have been computed for $H_2 + O_2 \Rightarrow H + HO_2$ and $H_2 + H_2(H) \Rightarrow H + H + H_2(H)$. These processes are important in hydrogen-air combustion. The first reaction is the key initiation step in the overall reaction mechanism. Its rate constant has not been directly measured in either forward or reverse direction. The latter process occurs in the exhaust nozzle of the scramjet engine of NASP. For this reaction, nonequilibrium effects must be considered because the overall recombination rate is sensitive to the relaxation rate of the nascent H_2 molecules formed in very high vibration-rotation levels.

As data are accumulated from these computational studies, they are recast in a suitable form for inclusion in the flow-field models and are made available to others in the aerothermodynamics community. During the upcoming year, these calculations will be extended to include chemical and physical processes likely to occur during high-speed entry into the Martian atmosphere and during the return to Earth from Mars.

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Aeroassist Flight Experiment Flow-Field Simulation

G. Palmer

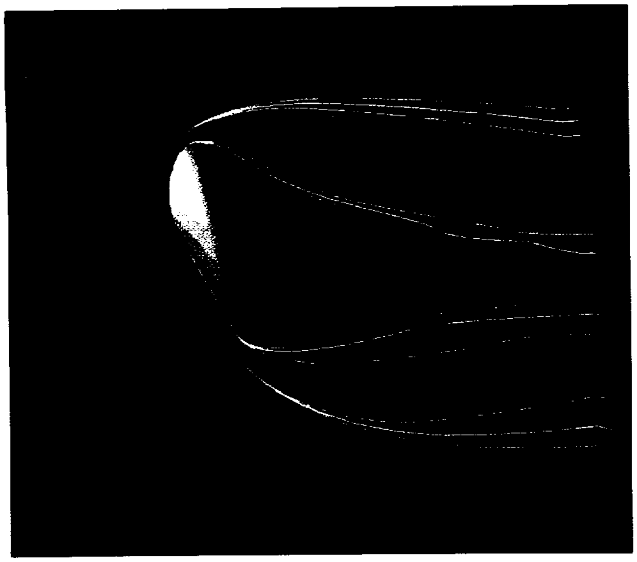
The aeroassist flight experiment (AFE) vehicle, a major element of NASA's Civilian Space Technology Initiative, is scheduled for launch in 1994. After it is released from the space shuttle, the AFE will pass through the Earth's atmosphere and be recovered by the shuttle. Its primary purposes are to demonstrate the viability of aerobraking as a means of planetary entry and to gather experimental data that will be used to validate real-gas computational fluid dynamic (CFD) codes.

The AFE will travel in the Earth's upper atmosphere at velocities ranging from 7 to 10 kilometers per second. At these conditions both chemical and thermal nonequilibrium effects will be significant. It is impossible to duplicate this flow regime in ground-based test facilities. Newly developed, real-gas Navier-Stokes codes will be used with older boundary-layer and viscous shock-layer techniques to approximate the aerodynamic and thermal loads the AFE will experience and to design the experiments carried aboard the spacecraft.

A three-dimensional (3-D), shock-capturing, fully coupled, finite-rate thermochemical nonequilibrium algorithm has been developed. It uses a two-temperature physical model to represent the dissociation, ionization, and the thermochemical nonequilibrium effects in the high-temperature region behind the bow shock. The full Navier-Stokes equations are solved using an explicit technique. A novel coupling method that limits changes in species mass fraction per iteration maintains stability while permitting a high global time step. Solution times are comparable to those obtained using implicit techniques.

Comparisons made against experimental and computational data validate the accuracy of the method. The code has been vectorized, reducing the time to compute one iteration at one point from 1.95×10^{-4} to 6.8×10^{-5} seconds. To compute a 3-D AFE flow field using this method requires about 60 hours on a Cray-2 computer.

A 3-D AFE flow field, including the base region, was computed at the proposed 77.8-kilometer trajectory point. Data from these calculations will be used to design the radiometer experiment to be carried aboard the AFE.



Aeroassist Flight Experiment vehicle at 77.8 kilometers, vibrational temperature contours (Kelvin)

The figure shows vibrational temperature contours in the symmetry plane of the AFE. The base region appears to be an area of strong nonequilibrium and complex fluid dynamic effects. The flow expanding over the shoulder of the vehicle chemically freezes, and there are complex recirculation patterns in the base flow.

The method has proven its ability to compute complex 3-D real-gas flows. Enhancements to the physical model will be incorporated into the code as they become available.

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Space Research

Pilot Land Data System

G. Angelici, L. Popovici, C. Wong

The Pilot Land Data System (PLDS) is a limited-scale, distributed information system designed to explore scientific, technical, and management approaches to satisfy the needs of NASA's land science community now and into the next century. The goal of the PLDS is to develop and implement a state-of-the-art data and information system to support research in the land-related sciences that will lead to a permanent research tool.

The PLDS is based on a distributed architecture that will use microcomputer workstations, supercomputers, and high-speed digital communications to form an operational capability with intelligent and useful services. From a local computer or terminal, an investigator can access a PLDS computer, conduct a complete search of the PLDS (and other) data holdings, and locate and possibly retrieve desirable data sets. The PLDS offers scientists additional services such as access to electronic mail, data analysis, supercomputer, on-line help, and file transfer capabilities. Goddard Space Flight Center manages the PLDS with Ames Research Center, Jet Propulsion Laboratory, and the university community participating.

The Ecosystem Science and Technology Branch at Ames is contributing to the development of the PLDS in the construction of a data and information system that serves the needs of two basic communities within the land science community—the community that uses aircraft imagery to accomplish its research objectives and the ecosystem science community.

A data base of remotely sensed imagery collected by various instruments mounted on high- and medium-altitude aircraft based at Ames has been constructed and made available to land scientists via dial-up connection and national networks. Over 19,000 Daedalus Thematic Mapper Simulator (TMS), NS001 TMS, Thermal Infrared Multispectral Scanner (TIMS), and aerial photographic images were inventoried on a Sun 4 computer at Ames using ORACLE data base management software. In the future, an inventory of ancillary data, such as flight request and calibration information, will be generated and offered to scientists.

The effort to serve the ecosystem science community will begin with a possible joint effort on an ecosystem science project in the Branch. An inventory of the project's data will be created and offered to the scientists with a user-friendly querying capability. Development of all newly created capabilities will be coordinated with other PLDS nodes and will be offered to all scientists served by PLDS.

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Concentration Determination of Free Radical Species

C. Chackerian, Jr.

Free radicals are very reactive chemical species which are ubiquitously found in energetic gaseous environments such as plasmas, shock waves, and combustion sources. It is often desirable to know the concentration of these molecules for such applications as quality control in the semiconductor industry or for the study of combustion environments.

A key molecular parameter required for determining molecular concentrations of free radical species by infrared absorption (or emission) spectroscopy is the absorption coefficient, which gives the probability that an infrared photon will be absorbed in a spectral transition of a particular molecule. Because radicals comprise an unknown fraction of any particular gaseous mixture, the absorption coefficients cannot be measured by the usual laboratory methods.

Recently, a subtle spectroscopic effect of the ClO [1] and NH [2] free radical diatomic molecular species was put into practice.

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The ER-2 Meteorological Measurement System

K. Chan

The NASA ER-2 aircraft is used as a platform for high-altitude atmospheric missions. The Meteorological Measurement System (MMS) was designed specifically for atmospheric research to provide accurate, fast-response, in situ measurements of pressure (±0.3 millibar), temperature (±0.3°C), and the three-dimensional wind vector (±1 meters per second).

Developed over a period of years and operational since early 1986, the MMS has participated in three major scientific expeditions: the Stratospheric-Tropospheric Exchange Project based in Darwin, Australia, in January and February of 1987; the Airborne Antarctic Ozone Experiment (AAOE) based in Punta Arenas, Chile, in August and September of 1987; and the Airborne Arctic Stratospheric Expedition (AASE) based in Stavanger, Norway, in January and February of 1989.

The MMS consists of three subsystems: (1) an air motion-sensing system, consisting of pressure, temperature, and airflow angle measurements, was installed on the ER-2 (NASA 706) to measure the velocity of the air with respect to the aircraft; (2) a high-resolution inertial navigation system (INS), dedicated to the MMS, was selected to measure the velocity of the aircraft with respect to the Earth; and (3) a lightweight, compact data acquisition system (DAS) was developed to sample, process, and record 45 independent variables at a sampling rate of 5 times per second.

The data acquisition software is customized and modularized to provide flexibility, redundancy of mass data storage, handling of read/write errors and temporary power malfunction, simultaneity of sampling 45 variables, asynchronous interface with the INS, and special programs for preflight checkout and postflight command. In the flight or stand-alone mode, the DAS runs the acquisition routine and logs data continuously; pilot interaction is limited to an on-off switch. In the ground or interactive mode, the user can execute any of the modular routines through an external terminal. Software is a key element of the MMS. It was written in the assembly language for compactness and speed.

To prepare the MMS for science missions, many sensor calibrations, system and transducer response tests, inflight calibration, and laboratory INS calibration were performed. The inflight calibration is a self-consistency test of the MMS measurements. It requires the pilot to fly the aircraft in special patterns and maneuvers at several altitudes. These inflight maneuvers are used to establish several calibration constants which are altitude and Mach-number dependent. The dynamic characteristics of the INS are calibrated on a tilted, physical pendulum in the laboratory. This calibration procedure can determine the time delay of each INS output variable to the nearest 0.01 second. Appropriate time shift is then applied to the data stream of each MMS-measured variable during processing.

The MMS provides detailed information of the atmospheric state variables and characterizes the atmospheric structure along the flightpath. Temperature and pressure measurements are extensively used by ER-2 investigators. Macroscale horizontal wind variations, together with temperature lapse rate measurements, are used to estimate the potential vorticity distribution and to study the mixing processes. Mesoscale phenomena of the MMS wind measurement, such as internal gravity waves, are analyzed to study the exchange processes of mass and chemical tracers between the stratosphere and troposphere. During the AAOE and AASE missions, well-defined signatures of orographically generated mountain lee waves were observed over the Palmer Peninsula in Antarctica and near Iceland in the Arctic region. Microscale variations of the vertical wind measurement are indications of fine-scale turbulence and can be used for flux calculations based on the eddy correlation technique.

Data from all airborne instruments were processed postflight during past atmospheric missions. Real-time wind computation capability has recently been developed for the MMS, because Johnson Space Center wants to assess if the ER-2 MMS, with a telemetry link, can provide real-time wind monitoring support of the Space Shuttle operation. The

ER-2 MMS real-time wind monitoring capability was successfully demonstrated August 8, 1989, at Kennedy Space Center during Space Shuttle STS-28 launch.

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Computer-Aided Boundary Delineation for Area Frames

T. Cheng, R. Slye, G. Angelici

Area frames—areas of land framed by political or natural boundaries—are constructs used as sampling vehicles for large area surveys. Compiled by dividing the area to be surveyed into contiguous parcels, each parcel is easily located on the ground and is suitable for a sample-based survey.

The National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture (USDA) uses area frames to select sample sites in its surveys of agricultural commodities. NASS's current procedure of compiling and editing area frames is slow, labor-intensive, and sometimes inaccurate. A computer-aided area frame procedure was designed and developed to transfer image-processing technology to NASS and to assist in collecting agricultural information.

NASS and the Ecosystem Science and Technology Branch (ECOSAT) at Ames Research Center have worked together for more than 10 years to integrate remote-sensing technology into the procedures used by NASS in gathering information. The latest cooperation between the two agencies is a NASS-sponsored research task at ECOSAT for developing software to create and edit area frames on a microprocessor-based workstation. In 1988, a 3-year proposal contract was awarded by NASA Headquarters, through the Earth Observation Commercial Application Program, for additional hardware and personnel.

As a result of software development for the California Cooperative Remote-Sensing Project (1985 through 1987), ECOSAT proposed to NASS the possibility of performing the area frame functions with display software on a workstation. Prototype software for this computer-aided area frame procedure was completed and tested in 1988. Named Computer-Aided Stratification (CAS), this software system stratifies sampling units by land use and land cover type by using image-processing hardware and software. With a background display of Landsat Thematic Mapper imagery and the corresponding U.S. Geological Survey Digital Line Graph data on a monitor, operators use a cursor to delineate agricultural lands, or primary sampling units (PSUs), which are assigned to strata of land use and land cover types. The resultant boundaries of PSUs are used as input into USDA sampling procedures and used in predicting agricultural statistics. As a test, three counties in Missouri were chosen to apply the CAS procedures in 1988 and 1989. Subsequent analysis indicated that CAS used only one-fifth of the time needed for the manual techniques in creating sampling units.

Current efforts are directed toward completing and upgrading the software, and implementing an operational hardware system. Ames recently procured a Hewlett-Packard (HP) 9000 Model 360 TurboSRX Graphics Workstation that will be interfaced with a Sun 3/260 computer workstation. This prototype configuration will be used as a basis for designing additional hardware and to develop the software for the operational system. Additional peripheral devices, such as an optical disk drive and a color printer, are being considered to enhance the performance of the procedure. The final configuration of the operational system at NASS, to be completed in 1991 and based on Ames' recommendations, will consist of up to six HP display stations networked to a data server.

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Airborne Arctic Stratospheric Expedition

E. Condon, S. Hipskind

The Airborne Arctic Stratospheric Expedition was conducted during January and February 1989 from the Sola Airbase just outside Stavanger, Norway. This mission was a follow-on to the 1987 Airborne Antarctic Ozone Experiment, the results from which directly implicated man-made chemical compounds in the "ozone hole" phenomenon. The primary objective of this experiment was to study the production and loss of ozone in the north polar region to determine whether similar conditions and photochemical mechanisms exist in the Arctic stratosphere as were found over the Antarctic. Emphasis was placed on determining the effects on the ozone distribution of the Arctic polar vortex and of the cold temperatures associated with the formation of Polar Stratospheric Clouds.

Fourteen flights each were made by the NASA ER-2 and DC-8 aircraft, using essentially the same complement of instruments as was carried on the Antarctic mission. Data were collected on the chemical, meteorological, and cloud-physical parameters necessary to characterize the dynamical and photochemical processes which affect the ozone. Data were also gathered from several satellite instruments and from global meteorological models to provide the large-scale context in which the aircraft measurements were made.

The expedition was an international effort with approximately 200 direct field participants in Stavanger. During the same period investigators at other Arctic locations were making both ground-based and balloon-borne observations, which were coupled either directly or indirectly with the aircraft campaign. U.S. contributors in both manpower and support were NASA, the National Oceanographic and Atmospheric Administration, the National Science Foundation, the National Center for Atmospheric Research, Harvard University, the University of Denver, Pennsylvania State University, and the Chemical Manufacturers Association. Within NASA, scientists and experiments came from the Ames Research Center, the Jet Propulsion Laboratory, the Goddard Space Flight Center, and the Langley Research Center. NASA Space Science and Applications and the Division for Earth Science and Applications provided science management and portions of the overall administration.

Aircraft instrumentation was developed under long-standing programs funded by the Upper Atmospheric Research and Tropospheric Chemistry offices of NASA's Earth Science and Applications Division.

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Remote Sensing of Forest Chlorophyll Content

P. Curran

Chlorophyll is a key indicator of the physiological status of a forest canopy. However, its distribution may vary greatly in time and space, so that the estimation of canopy or branch levels of chlorophyll content by extrapolation of destructively obtained leaf values is labor-intensive and potentially inaccurate.

Chlorophyll content is related positively to the point of maximum slope in vegetation reflectance spectra which occurs at wavelengths between 680 and 740 nanometers and is known as the "red edge." A spectroradiometer was used to measure the red edge of needles on individual slash pine branches and in whole forest canopies at a University of Florida/National Science Foundation-sponsored field site in northern Florida. Branches were measured on the ground against a spectrally flat reflectance target; canopies were measured from atop observation towers against a spectrally variable understory and forest floor.

There was a linear relationship between the red edge and chlorophyll content of branches ($R^2 = 0.91$). Measurements of the red edge and this relationship were used to estimate the chlorophyll content of additional branches with an error that was lower than that associated with the wet laboratory method.

There was no relationship between the red edge and the chlorophyll content of whole canopies. This can be explained by the overriding influence of understory and forest floor, an influence that was illustrated by spectral mixture modeling.

The results suggest that the red edge could be used to estimate the chlorophyll content in branches, but it is not likely to be of value for estimating chlorophyll content in canopies unless the canopy cover is high.

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Remote Sensing of Seasonal Forest LAI

P. Curran

Accurate seasonal estimates of leaf surface area (LAI, area of leaves per unit area of ground) are essential for accurately determining every energy and material exchange between plant canopies and the atmosphere. Such estimates are very difficult to obtain for forests where canopy access is difficult and foliage is distributed heterogeneously.

Building upon theoretical studies, researchers have recently developed powerful predictive relationships between remotely sensed data recorded by the Thematic Mapper (TM) on the Landsat satellite and forest LAI. These relationships are based upon annual averages of LAI derived from relationships between LAI and readily-measured tree dimensions (e.g., diameter). Therefore, they cannot be used to estimate seasonal LAI.

As part of a University of Florida/National Science Foundation study, the LAI of 16 slash pine plots in north Florida were measured monthly, in the field, from mid-1986 to mid-1989. These measurements were the first of their kind.

Three Landsat TM scenes from February 1988, September 1988, and March 1989 were purchased. There was a linear relationship between LAI and remotely sensed data with R_2 of 0.35, 0.75, and 0.86, respectively. Data from half of the plots were used to estimate the LAI in the other plots on each date with a mean root mean square error of 0.74 LAI.

This is the first reported use of Landsat TM to estimate seasonal LAI and opens the way for using these data for predicting subtle responses by the forest canopy to changing environmental conditions and the modeling of canopy processes for large areas of terrain.

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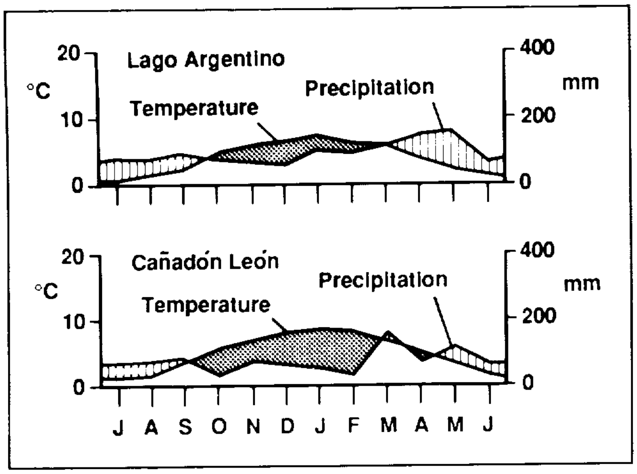
Palynology in Patagonia: From Space to Time

H. D'Antoni, M. Mancini

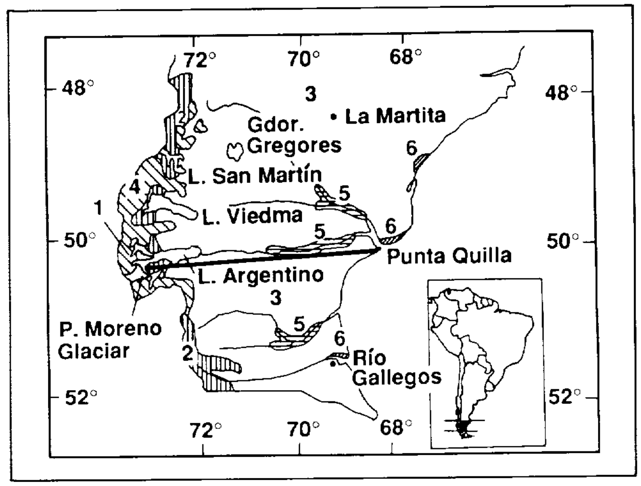
Numerical models based on remote-sensing imagery are powerful tools to predict changes that the Earth will suffer in the next decade to century, both by natural causes and in response to human activities. Data bases with long time scales and detailed land-based observations are necessary to improve those models.

Modern pollen analysis offers an accurate picture of modern environments to match satellite imagery of vegetation. Quaternary pollen analysis describes the process, controlled by climate and other environmental factors, that brought ancient vegetation to its present configuration. The comparison of modern and fossil pollen records provides the clues to translate gradients of modern configurations into past vegetation processes. Moreover, it discloses paleoclimate that in turn becomes the link between short and long time scales needed to build predictive models.

Modern pollen data from a transect between the Andean foothills on the west and the Atlantic shore on the east, at latitude 50°S, were compared with fossil pollen data from a sedimentary profile of a rock shelter (Cueva 4 de La Martita, at latitude 48°S) used by people of Toldense (8,000 years before present (BP)) and Casapedrense (4,500 BP) archeologic cultures. The pollen content of 29 surface soil and 17 stratified sediment samples was analyzed.



Climate diagrams of Cañadón León and Lago Argentino



Location of Cueva 4 de La Martita in relation to modern vegetation and the modern pollen transect (solid line) between Glaciar Perito Moreno and Punta Quilla

Subsequently, the analytic data were factor-analyzed and 5 factors were obtained. Factor 1 (F1) describes the cool and arid grasslands of Central Patagonia, as found around Cañadón León (150 millimeters annual precipitation and 9°C mean annual temperature, shown in the first figure). Factor 2 (F2) relates to more humid locations within an arid environment (grasslands with remarkable proportions of Compositae, as found today on the southeastern shore of Lago Argentino, 190 millimeters annual precipitation and 7°C mean annual temperature, shown in the first figure).

Factor 3 (F3) relates to the western humid grasslands. Factor 4 (F4) corresponds to the coastal saltflats, on the east. All these environmental divisions are included under number 3 in the second figure. Factor 5 (F5) corresponds to the Subantarctic forests of Nothofagus spp. (the southern beech), number 2 in the second figure.

The fossil samples of La Martita associated either to F1 or F2. A pollen diagram of the modern-fossil comparison (probabilities of the dominant pollen types) is shown in the third figure. The results of factor analysis and the reconstructed environmental history are shown in the last figure.

From the earliest level (tentatively placed at 10,700 BP) up to 8,000 BP, the environment was F1 (xeric); between 8,000 and 6,500 BP it was F2 (humid); between 6,500 and 5,900 BP it was F1 (xeric); by 5,800 BP the environment was F2 (humid); between 5,500 and 2,500 BP it was F1 (xeric); and from then on to the present, F2 (humid).

These results indicate that fluctuations of 40 millimeters in annual precipitation and 2°C in the mean annual temperature occurred in this region during the last deglaciation. Arid grasslands developed during more xeric periods, and grasslands plus Compositae developed during the humid ones. The impact of the archeologic cultures Toldense and Casapedrense on the regional environment is not evident in the pollen record.

In light of these findings, current models for climate should be calibrated to predict regional climate, as fluctuations of similar magnitudes in arid or semiarid regions of midlatitudes may occur.

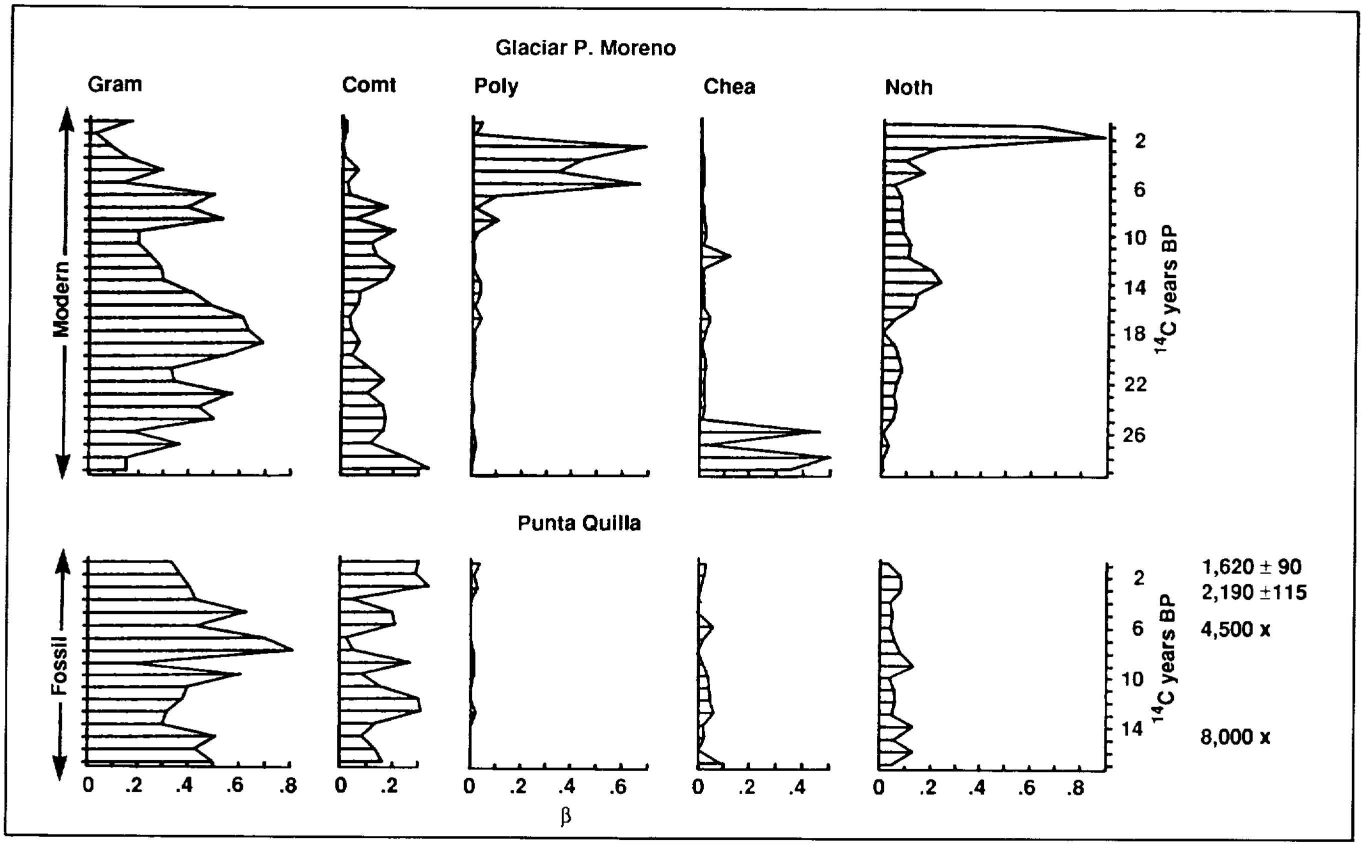
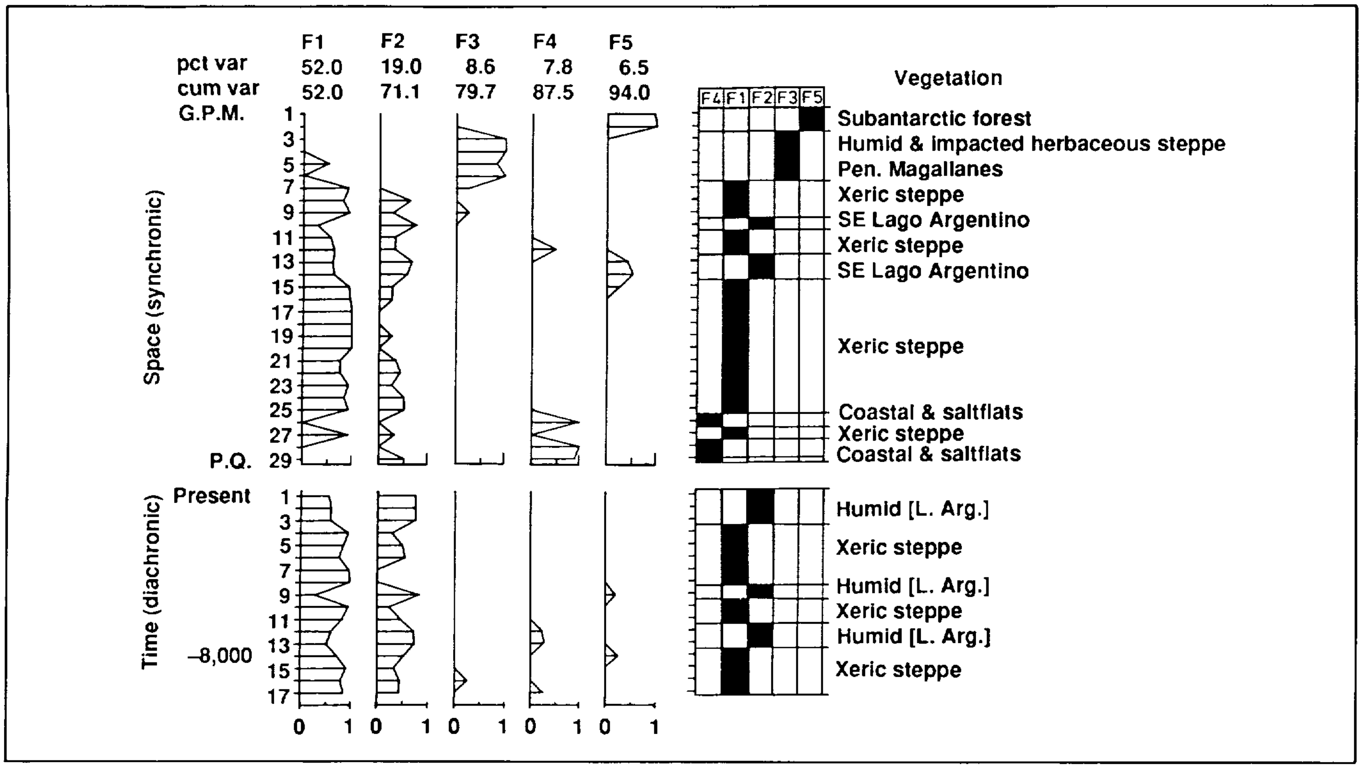


Diagram of the modern pollen transect (above) between Glaciar Perito Moreno and Punta Quilla. La Martita record (below) with ^{14}C datings on the right column. Scale is estimated probability. (*) two ^{14}C dates. (~) estimated



Factor loadings of the samples on each factor. Factors and observed vegetation (right side, above); factors and inferred vegetation (right side, below)

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Analysis of Cirrus Cloud Radiation Measurements

P. Hammer, F. Valero

The properties of cirrus clouds in the Earth's atmosphere using radiance measurements acquired from satellite and aircraft platforms are being studied. To interpret these measurements, analysis techniques which invoke modern radiative transfer theory were developed. These methods were applied to thermal infrared data obtained during a recent coordinated field experiment, project FIRE (first international satellite cloud climatology project regional experiment), supported by the NASA climate research program. Several satellites and aircraft were involved.

The study has elucidated particular midlatitude cirrus attributes, such as ice crystal sizes and cloud optical depths, which are important determinants of the radiative effects of the cirrus on the Earth's atmosphere and ultimately on the climate. Specifically, our results have supported evidence that the ice crystals tend to be significantly smaller than 50 micrometers across. This has implications for models of cirrus cloud evolution. Using satellite, as well as aircraft, remote-sensing data has the advantages of enabling comparative multiple platform studies and the extension of results to broad regions covered by the satellite.

A feasibility study indicated that the methods may also be applied to tropical cirrus studies. This is the subject of a proposal that was recently submitted to the NASA Upper Atmosphere Research Program for analyzing measurements from the Stratosphere-Troposphere Exchange Project.

In addition to their role in the Earth's radiation budget, tropical cirrus clouds are considered to play a significant role in the exchange of mass across the tropopause. Understanding the nature of the mass transfer processes is important for predicting the effects on stratospheric ozone of molecular species originating in the lower troposphere. Analysis of multiple platform radiance measurements of such clouds can help to reveal their microphysical and optical properties which in turn can elucidate dynamical processes at the tropopause caused by radiative processes.

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An Open-Path Diode Laser Fluxmeter for Measuring Biogenic Trace Gases

G. Livingston, J. Podolske

The goal of this project is to develop field instrumentation to accurately measure the flux of biogenic trace gases at the Earth's surface using micrometeorological eddy correlation theory. Current in situ techniques for measuring trace gas flux are subject to critique, as all interfere with the flux processes to an unknown degree and are subject to the high spatial and temporal variability characteristic of many soil microbial communities.

This project seeks to adapt and verify a prototype instrument developed by Aerodyne Research, Inc., under NASA's Small Business Innovative Research Program for making quantitative measurements of the surface-to-atmosphere flux of selected trace gases. This instrument integrates the fast response and quantitative accuracy of laser spectroscopy with micrometeorological techniques in a unique open-path design which imposes no interference with the vertical motion of the near-surface air mass. Other instrument designs, in contrast, require considerable handling of atmospheric samples.

The prototype instrument has demonstrated stability and sensitivity beyond any known instrument for measuring trace gas flux. The planned modifications are to streamline the aerodynamics of the instrument, to dramatically reduce the power requirements, and to prepare the instrument for extended tower-based field operation. The power reduction will be achieved largely by replacing the cryogenically cooled laser with a state-of-the-art model that can be operated at liquid nitrogen temperatures (77 Kelvin). Laboratory and field evaluations of the modified instrument are planned for spring 1990.

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Nitrogen Transformations and Volatization from a Subtropical Pasture Ecosystem

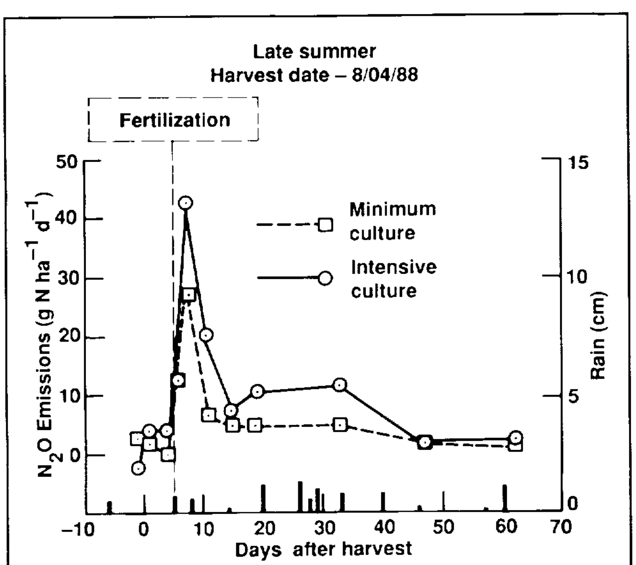
G. Livingston, G. Brams, G. Hutchinson

Nitrous oxide (N_2O) is a long-lived trace atmospheric constituent, the concentration of which has risen steadily (0.2% per year) over the past three or four decades. It functions both as a potentially important greenhouse gas and as a participant in reactions leading to the destruction of stratospheric ozone. Nitric oxide (NO), in contrast, is a short-lived species which significantly affects local to regional scale tropospheric chemistry. Combustion and soil microbial processes are the major sources of both species.

Among biogenic sources, tropical forest and grassland soils are known to contribute a disproportionately large share of the global flux of N_2O, but little is known about emission rates from comparable subtropical ecosystems or NO emissions. Subtropical grasslands, because of their large geographical extent and because most are subject to intense management or disturbance practices, may also represent a significant, albeit seasonal, source of nitrogen oxide gases.

This study is focused on nitrous oxide emissions from intensively managed pastures in the humid subtropical climate of the Gulf Coast of Texas. It is being conducted within the auspices of a NASA Minority University Research Program award to Prairie View A&M University (Texas) and in concert with a U.S. Department of Agriculture study on NO emissions from the same study sites.

To date, the diel and seasonal variabilities of N_2O emissions have been characterized in relation to management practices and soil environmental and nitrogen-cycling parameters. Preliminary results indicate, as expected, that N_2O emission rates from grasslands subject to intensive cultural management (regular harvest and fertilization) are significantly higher than from sites which are only minimally managed (see the figure). Emission rates are strongly seasonal and appear to be largely the result of nitrification. Measured fluxes more closely resemble the low emission rates characteristic of temperate region grasslands than the high rates characteristic of the tropics. Analyses of the soil nitrogen transformation rates and statistical analyses of both the NO and N_2O gas emissions data are under way.



Nitrous oxide emissions in response to harvest and fertilization

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Estimating Regional Methane Flux in Northern High-Latitude Ecosystems

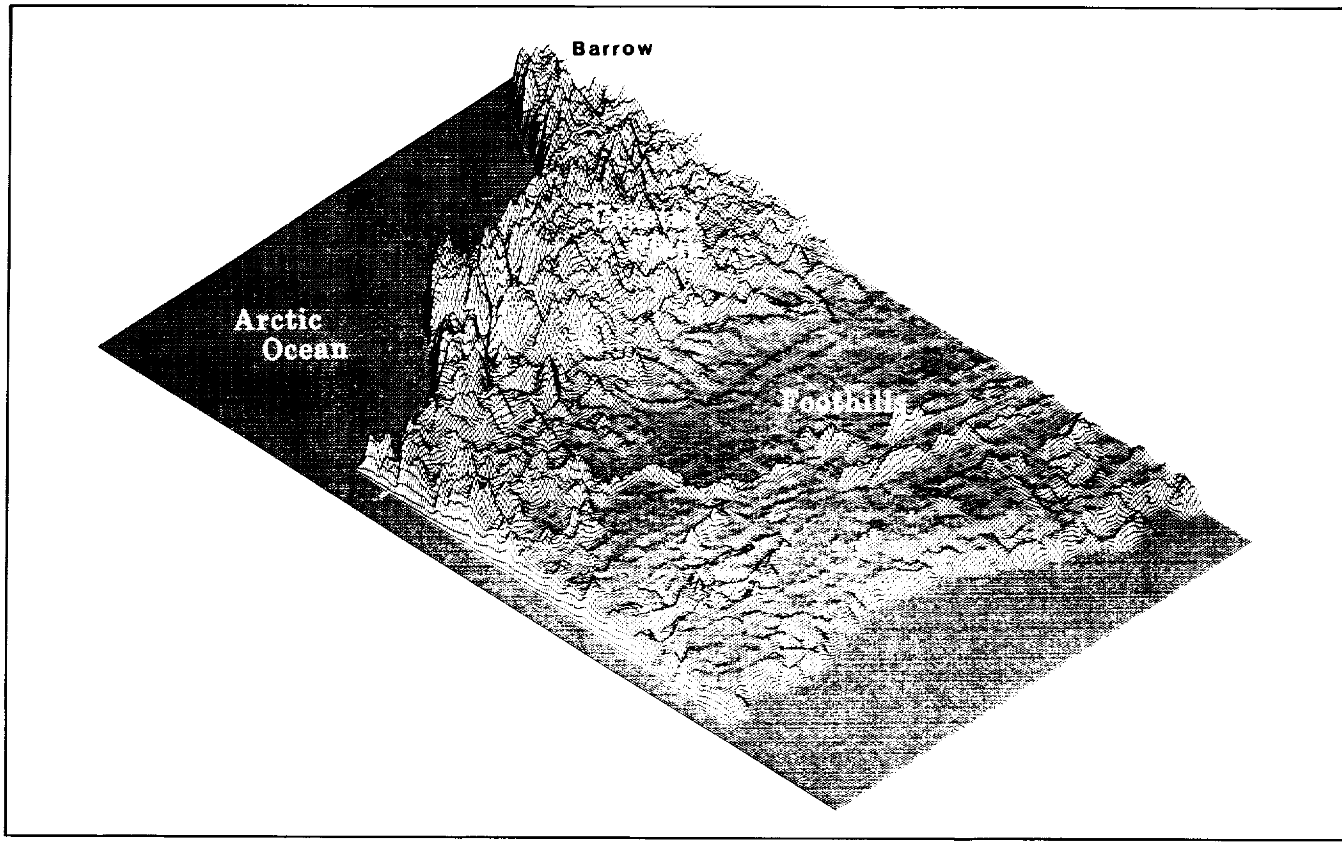
G. Livingston, L. Morrissey, D. DesMarais

Methane is one of the most chemically and radiatively active trace gases in the atmosphere, participating in the chemistry of both the troposphere and stratosphere, and significantly contributing to the global "greenhouse effect." During the past century the atmospheric concentration of methane has dramatically increased in proportion to that of the Earth's human population and is continuing to increase at a rate of about 1% per year.

Although global methane sources are diverse, globally distributed, and very poorly quantified, the present day sources, both natural and anthropogenic, must be understood if we are to predict with confidence the impact of the observed methane increase on the Earth's climate and atmospheric chemistry.

Microbial decomposition processes in the waterlogged, carbon-rich soils characteristic of the northern high-latitude tundra (treeless) and taiga (forested) wetland ecosystems are perhaps the largest natural source of atmospheric methane. These ecosystems are particularly important because of their extensive areal coverage and because of the vast carbon resources stored in these frozen peatland soils that would become available for decomposition should a climatic warming occur. The major obstacle to understanding these ecosystems has been the lack of information on their complexity and variability over space and time.

The goal of this project is to integrate in situ and remote-sensing observations into an ecological



Methane emission rates over a 80,000 square kilometer area on the Alaska North Slope. Note the high emission rates from the waterlogged peat soils of the Coastal Plain and drainage basins in contrast to the low emission rates from the well-drained soils of the Arctic Foothills

model that will quantitatively estimate methane flux from these high-latitude ecosystems on seasonal and regional (10^3 km^2) scales. The initial regions of study are the Arctic North Slope and Tanana River Valley of Alaska. Hydrological and vegetation characterizations, derived from 80-meter Landsat Multispectral Scanner and multitemporal 1-kilometer Advanced Very High Resolution Radiometer satellite data, have been employed in a statistical approach which quantitatively aggregates methane flux measurements from local to regional-seasonal scales (see the figure). These results confirm that wet tundra ecosystems are seasonally important to the global methane budget, although estimates based upon the satellite stratifications are significantly lower than previously published results. The need for incorporating remote sensing into regional ecosystems studies has been clearly identified. The results suggest that current methane emission estimates for northern ecosystems at the global scale may be seriously biased due to inaccurate areal estimates for these ecosystems and inappropriate methodologies for scaling up local measurements.

Continued efforts under funding from the Interdisciplinary Research Program in Earth Sciences will focus on the northern forested wetlands which are significantly more complex than the tundra ecosystems. The use of Synthetic Aperture Radar and high spatial resolution infrared sensors in combination with Landsat sensors will be explored in depth. Studies on the stable carbon isotopic composition of methane will provide an independent estimate of regional methane flux from these ecosystems. Additionally, soil thermal and hydrological process models driven by surface observations will be examined in relation to methane emissions.

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Nitrous Oxide Flux from Tropical Forest Ecosystems

P. Matson, P. Vitousek, C. Volkmann

Understanding the sources and sinks of trace gases in Earth's atmosphere, and the effects of human-induced change on them, is necessary for predicting long-term climate change and the effect of anthropogenic change on global habitability. Considerable evidence suggests that tropical ecosystems, now undergoing very rapid change, are important sources of many trace gases. The role of tropical forests in global energy and element cycling and the extent to which land conversion will affect that role are being examined as components of the Biospheric Research Program, Life Science Division, Ames Research Center.

Nitrous oxide is one of several biogenic greenhouse gases (with other important atmospheric roles) whose atmospheric concentrations are increasing. To understand the role of tropical ecosystems in this flux, nitrous oxide flux and the nitrogen cycling processes that control flux have been measured in tropical forests selected along gradients of soil fertility and climate.

Results from these studies suggest a flux of 2.40 teragrams/year from humid to wet tropical forests, a value considerably lower than estimated in other tropical budgets, but still more than any other natural source. Studies of fluxes from pastures in Amazonia suggest that tropical rain forest conversion to pasture may contribute another 0.7 teragrams/year, and thus may be responsible for approximately 25% of the measured annual atmospheric increase.

To date this research has focused primarily on humid and wet tropical forests. Dry and seasonally dry tropical forests, which account for one-third of the total tropical forest area, have not been examined by any research group. Our preliminary data suggest very low (often zero) fluxes from these dry forests during the dry periods, and fluxes similar to humid forests during the wet season. These forests may contribute an additional 1.0-1.5 teragrams/year to the global budget.

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Gravity Waves, Turbulence, and Radiative Heating in the Tropical Lower Stratosphere

L. Pfister

Convective systems in the tropical regions are believed to be the major mechanism by which air and associated trace constituents are transported from the lower atmosphere (the troposphere) upward into the stratosphere, which contains the ozone shield. One of these trace constituents is the family of man-made chlorofluoromethanes. Since these are produced in the troposphere and transformed into ozone-destroying reactive species in the stratosphere, their transfer between these two regions is an important factor in understanding (1) why the amount of stratospheric ozone over midlatitude regions has decreased by some 5% during the last 15 years, and (2) what future reductions in ozone amounts can be expected.

The Stratosphere-Troposphere Exchange Project (STEP) was designed to answer some of these questions. The project has sponsored three high-altitude aircraft field experiments, one of which (January 1987) was designed to address the question of tropical exchange associated with convective systems. Included in the measurements were meteorological variables (temperature, pressure, and wind vector), radiation, particles, and various stratospheric and tropospheric trace gases. The complement of trace gases enables us to establish the origin of a particular air mass (e.g., stratosphere or troposphere), while the meteorological and radiation measurements can establish the mechanisms by which such an air mass can be transferred from the troposphere to the stratosphere or vice versa.

Two basic types of transfer mechanisms have been either discovered or confirmed by STEP: dynamically induced mixing by turbulence and radiational heating. Perhaps the most important new results are in the areas of lower stratospheric turbulence.

STEP has made wind measurements at the tops of tropical anvils available for the first time. These wind measurements are sufficiently precise to allow us to distinguish between waves (which are reversible phenomena with no direct significance for mixing) and turbulence, which can irreversibly mix tropospheric and stratospheric trace gases upward and downward, respectively. These measurements have shown that the strong shears above a tropical cyclone (which are caused by bringing surface air into proximity with the mean easterly jet stream at the Australian tropopause) induce significant turbulence near the anvil top. This turbulence is quite widespread, and is sufficient to mix air irreversibly over a depth of ~1 kilometer.

STEP measurements have also shown that gravity waves with horizontal scales ranging from 5 to 100 kilometers are generated by overshooting turrets and expanding mesoscale anvils. On at least two occasions during STEP, these gravity waves generated wind shears that were large enough to induce shear instability and subsequent irreversible mixing.

Analysis of trace gas profiles yields clues about radiative heating as well. Instances where potential temperature increases with altitude, but trace gas mixing ratios do not, are suggestive of radiative heating. STEP showed numerous instances of these kinds of profiles. In many cases, these were downwind of a convective system or associated with high ice crystal concentrations. This showed clearly that strong heating of an ice crystal layer containing tropospheric air had occurred, contributing to troposphere-to-stratosphere transfer.

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Nitric Acid in Polar Stratospheric Clouds

R. Pueschel, K. Snetsinger

Microchemical spot analytic techniques have been adapted to stratospheric aerosol particles collected on wire impactors aboard the ER-2 research aircraft. In particular, the reaction of condensed nitric acid particles with nitron on wire impactors permits the detection of this important compound.

An analysis of the samples as a function of temperature shows a temperature threshold $T_t = 194 \pm 3$ Kelvin that is identical to that of polar stratospheric cloud formation. The conclusion is that polar stratospheric cloud particles, detected regularly by the Stratospheric Aerosol Measurement II satellite sensor in winter in both hemispheres since its inception in 1978, are composed of nitric acid.

This experimental proof of the existence of nitric acid in polar stratospheric clouds lends credibility to the theory that the surfaces involved in heterogeneous stratospheric ozone depletion are formed from condensed nitric acid. This is a prerequisite for the conversion of inert chlorine nitrate to chlorine radicals, partially derived from chlorofluorocarbons, which can catalytically convert ozone to oxygen.

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Algal Spectral Reflectance Signatures

L. Richardson, D. DesMarais, R. Wrigley

This research is aimed at determining the spectral reflectance signatures of the major groups of algae and photosynthetic bacteria. Each major taxonomic group possesses a specific set of photosynthetic pigments that absorb light for photosynthesis. This specific pigment composition can be detected by light reflected from populations of such photosynthetic microorganisms both in the natural environment and in the laboratory. The spectral signature can also be detected by high-resolution remote-sensing instruments.

The long-term application of this research is the use of remote sensing to study aquatic biogeochemistry. We are using ground-based spectroradiometer measurements to support analysis of satellite images of a research site in Mexico where we are studying ecosystem-level carbon and nitrogen cycling in hypersaline ponds and coastal lagoons. In addition to analyzing the reflectance spectra of each group of microbes, we are quantifying the photosynthetic pigments and the type of microbe present. This approach is also being used to study the relationship between climate and the emission of sulfur gases (dimethyl sulfide) by phytoplankton in the marine environment.

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Manganese Biogeochemistry in a Eutrophic Lake

L. Richardson, R. Wrigley, K. Nealson, E. Mills

The manganese cycle in Oneida Lake, New York, is being studied by using a combination of laboratory, field, and remote-sensing techniques. The remote-sensing approach is to measure surface chlorophyll concentration by using Landsat Thematic Mapper data and data from the Airborne Ocean Color Imager flown on the ER-2 aircraft. Surface chlorophyll data are then used to obtain lakewide estimates of manganese cycling events.

Field measurements and remote-sensing research are supported by in-depth laboratory studies on mechanisms by which both phytoplankton and bacteria mediate manganese biogeochemistry.

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Potato Production Estimates from the Columbia Basin

J. Salute

This project supports the goals of both the Office of Space Science and Applications and the Office of Commercial Programs, NASA Headquarters, by developing and transferring government- and university-developed remote-sensing techniques to a commercial entity for the economic benefit of the United States.

During 1989, research and technology transfer focused on refining application-specific techniques for developing potato production forecasts for the Columbia Basin. Potato production is estimated by measuring the total number of acres planted in potatoes and multiplying this by the estimated yield per acre. The total acreage is measured through digital image processing of Landsat multispectral scanner and thematic mapper data. Yield is estimated through a model that is being developed by the Agricultural Engineering Department at Oregon State University. This model incorporates spectral profiles of the potato crop as measured by field instruments, weather, and farming practices.

Results of the 1989 potato crop production estimates were distributed to the customers before other predictions were available. In a supply-driven market, timeliness of this reliable prediction is the key to commercial success.

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Instrument to Measure Leaf Light-Scattering Properties

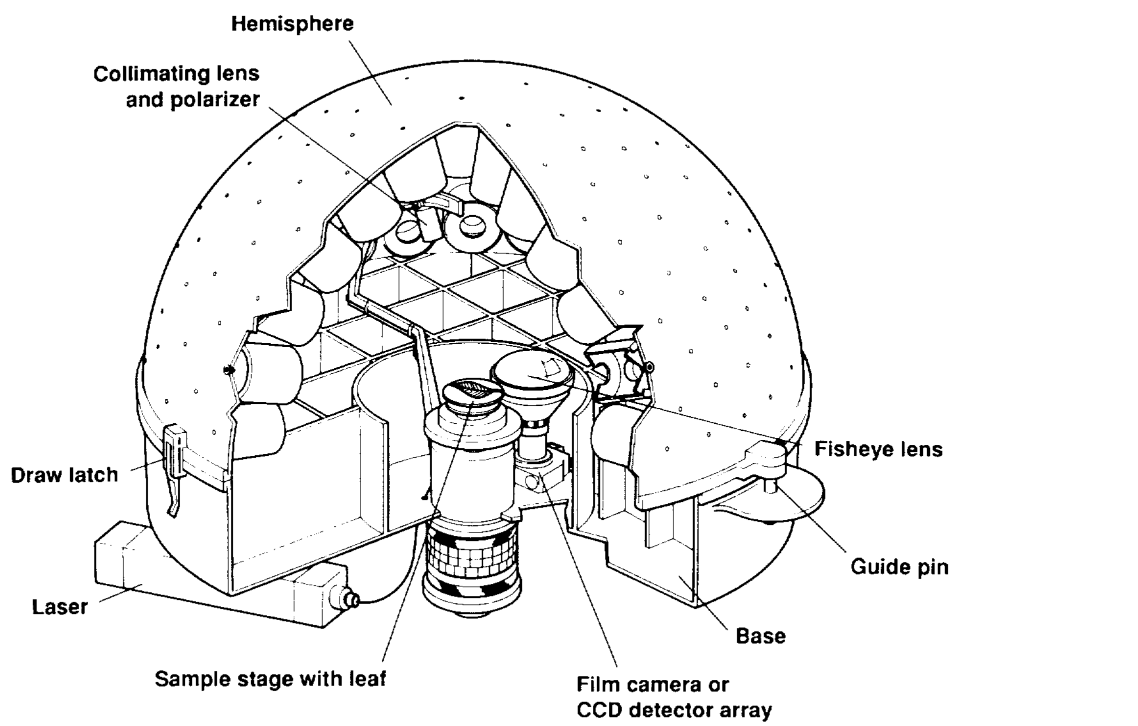
A. Sarto, C. Woldemar, V. Vanderbilt

The light-scattering properties of leaves are used as input data for models which mathematically describe the transport of photons within plant canopies, thereby providing insight into interpretation of remotely sensed imagery of the Earth. In seeking to quantify these properties, we have constructed a unique instrument (shown in the first figure) for rapidly determining the bidirectional reflectance factor (BRF) of leaves illuminated by linearly polarized light from a helium neon laser.

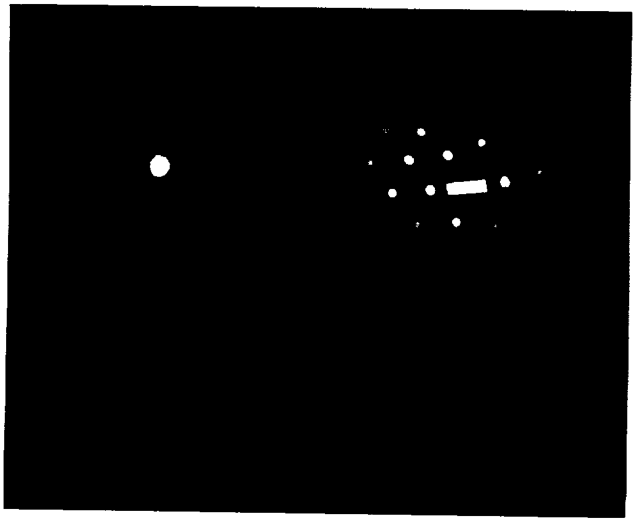
During measurement, light scattered by the leaf (at the center of the hemisphere) is reflected by white discs attached to the black inner surface of the sphere. With the aid of a fisheye lens and camera, the "brightness" of each disc is recorded on film, which is calibrated to estimate the BRF of the leaf.

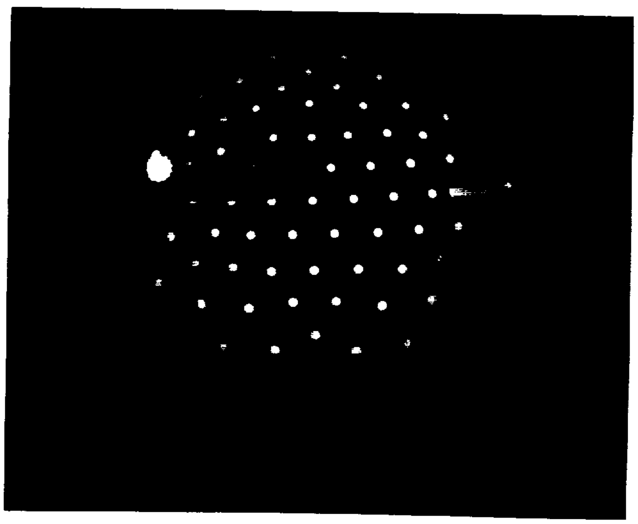
Results show that for the leaves of some species the BRF strongly depends upon the linear polarization of the incident light. For example, results for a magnolia leaf (see the second figure) show large differences in the bidirectional light-scattering properties depending on whether the electric vector **E** is parallel to the foliage surface.

In the second figure, the two interior views of the instrument, taken with the fisheye lens, show the amount of light scattered by the leaf (represented by the brightness of the white discs) illuminated by light having one of two polarizations. The incident laser light is shown as a very bright dot on the left of each image. In one image the leaf is a pronounced specular reflector, preferentially illuminating discs near the specular direction (the rectangular target which is located at the Brewster angle). For this first image, the **E** vector of the incident light was perpendicular to the plane of incidence. In the second image for which the **E** vector was parallel to the plane of polarization, the discs are more uniformly bright across



Cutaway of the instrument





Measurements of a magnolia leaf

the image, which suggests that the leaf is a more diffuse surface to this polarization.

These results are forcing a rethinking of the mathematical formulation of canopy photon transport models. At present, these models neglect the polarization effects which our results demonstrate are important to include.

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Analysis of Forest Disturbance Using Satellite Data

M. Spanner, C. Hlavka

Coniferous forests of the western United States are an important natural resource in terms of timber production and nutrient cycling. These forests have been severely impacted in recent years by disturbances caused by logging and fires. Because of logging practices, many of the forests in the western United States are a patchwork of clearcuts of varying sizes and ages. The objective of this research is to characterize the stages of disturbance and regrowth in coniferous forests of the western United States using satellite remote-sensing data from the National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer (AVHRR) which provides data over regional scales, and the Thematic Mapper (TM) on Landsat-5 which provides data over local scales.

Three stages of forest disturbance and regrowth that are important for nutrient-cycling research have been identified and can be discriminated by satellite-based remotely sensed data. These stages are (1) recent clearcuts, (2) regrowth of successional vegetation, and (3) mature coniferous forests. A model was developed which determined the proportions of these three forest cover types using a combination of TM and AVHRR data. Results indicate that there are predictable relationships between TM spectral response and the disturbance classes. Spectral signatures developed for the AVHRR data based on TM proportions were consistent with the TM spectral signatures. Preliminary analysis indicates that proportions of these disturbance types can be distinguished from AVHRR data over large areas, allowing the regional determination of forest disturbance for nutrient-cycling research.

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Dynamics of Waterfowl Winter Habitats in California's Central Valley

L. Strong

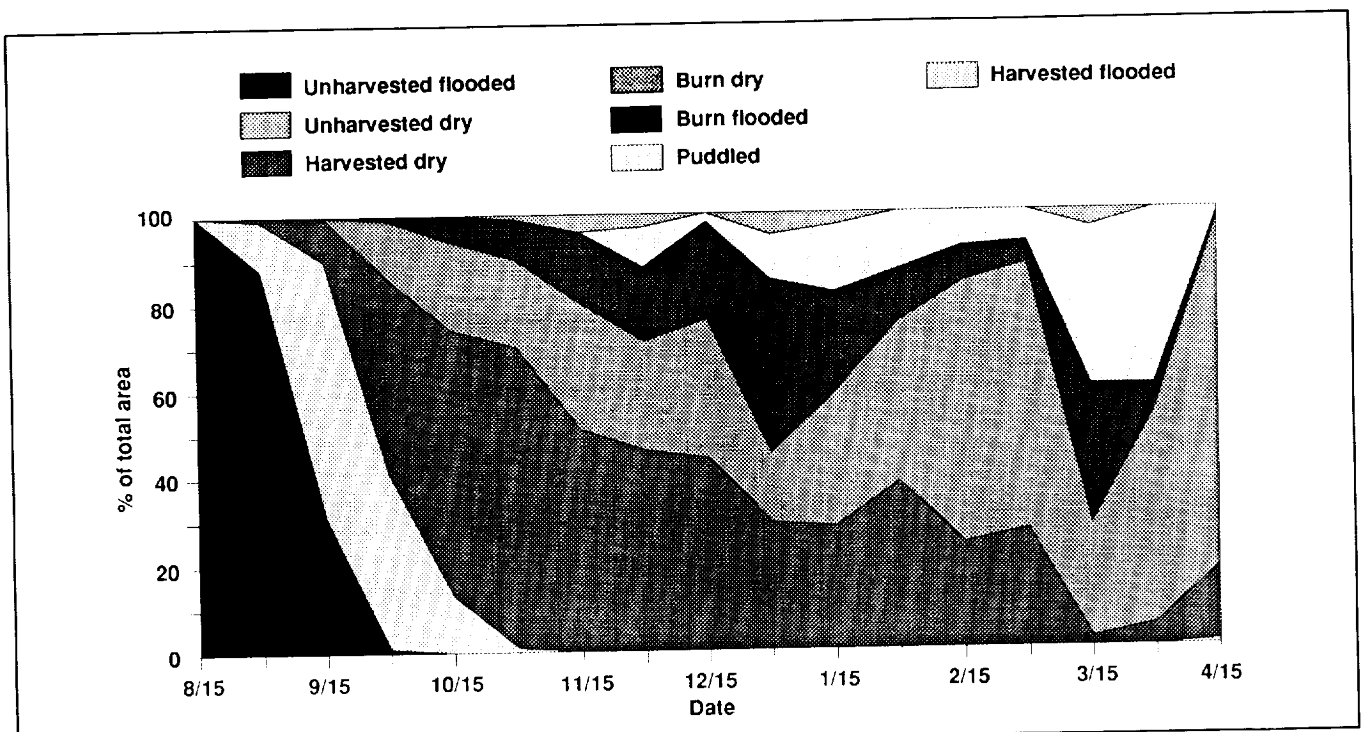
California's Central Valley provides a winter habitat critical to the survival of migratory waterfowl, a unique international resource that provides economic as well as aesthetic and scientific values to humankind. About 60% of the Pacific Flyway and nearly 20% of the continental population of wintering waterfowl are found in the Central Valley.

Today, only 5% of the originally estimated 4 million acres of wetlands exist as federal, state, and private lands maintained by seasonal or controlled application of water. In addition to managed habitats, several hundred thousand acres of additional land is of potential use to waterfowl. These areas are composed of bypasses for flood waters, grasslands, riceland, and other small grain croplands which are valued as food sources and resting areas by waterfowl.

The tremendous diversity of these habitats makes it difficult to assess their value to waterfowl without innovative remote-sensing capabilities. The figure shows changes in the area of rice fields, an important waterfowl habitat in the Sacramento Valley, under different agricultural management practices for the winter of 1988-1989.

The research explores the diversity, spatial distribution, and temporal dynamics of migratory bird winter habitats using multispatial, multitemporal, and multispectral remotely sensed data in conjunction with traditional ground and aircraft surveys. Research activities include separability analysis and feature selection for wetland habitats, evaluation of image processing and classification methods, spectral mixture modeling, change detection, and identification methods. Results of the research are used in conjunction with field studies of migratory bird behavior to study topics in waterfowl ecology including habitat selection, survival, energetics modeling, and impacts of agricultural contaminants.

Technology transfer is an important part of our research, which is conducted in cooperation with the U.S. Fish and Wildlife Service, Northern Prairie



Area of rice under different agricultural management practices in the Sacramento Valley from August 15, 1988 to April 15, 1989. The management practices present waterfowl with winter habitats of varying quality

Wildlife Research Center Field Station in Dixon, California. Presentations of the research are made to organizations including Ducks Unlimited and the Central Valley Habitat Joint Venture (the California component of the North American Waterfowl Management Plan). This research provides an evaluation of change-detection methodologies using remotely sensed data with coarse and fine spatial resolution in a variety of ecosystems and will provide insight to complex questions pertaining to monitoring global change.

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The Climatic Effect of Arctic Haze

F. Valero, W. Gore, P. Pilewskie

The northern polar atmosphere, free from pollutants for much of the year, undergoes seasonal episodes of pollution in late winter and early spring when the prevailing winds transport anthropogenic aerosols and gases from industrial regions in central and eastern Europe. At any latitude, the addition of particles to the atmosphere may alter the amount of solar energy that the atmosphere absorbs, reflects to space, or transmits to the Earth's surface, which may potentially influence climate. Polar regions, however, are particularly sensitive because of the highly reflective ice surface. Under clear conditions, most of the solar radiation is reflected back to space by the surface-atmosphere system. If the absorption of solar energy in the Arctic atmosphere were to increase, the effect of the energy imbalance might be such that climate would be altered on a local, or perhaps even global, scale.

The Arctic Gas and Aerosol Sampling Program (AGASP) was an international collaboration to determine the concentrations and compositions of the gases and aerosols which make up the Arctic haze, as well as the effect of the haze on the solar radiation flux within the atmosphere. Phase I of this study was completed in 1983, phase II in 1986, and phase III in March 1989. Our group, participating in all three phases of AGASP, built and used state-of-the-art optical instrumentation to measure the absorption of solar energy within the haze (from which atmospheric heating rates were deduced), the thickness of the haze layers, the total solar spectrum energy flux, and both the direct and diffusely scattered solar radiation fields at specific wavelengths of interest, used to infer the vertical distribution of the absorbing particulates. The instruments were carried aboard the NOAA WP-3D research aircraft which flew at several levels in the atmosphere.

We have also developed the computational models necessary to derive climatically important quantities. The following results from AGASPII can be reported:

1. increase in the total solar energy absorbed in the lowest kilometers of the atmosphere, by about 30 to 40%, over haze-free conditions,
2. decrease in the total energy absorbed by the ice surface by 6 to 10%,
3. increase in the total solar energy absorbed by the atmosphere-surface system by 10 to 15%,
4. changes in instantaneous heating rates as large as 0.6 Kelvin/day.

Before the most recent leg of AGASP, completed March 1989, we improved the performance of a new instrument, the Total-Direct-Diffuse Radiometer, by modifying data acquisition and sampling techniques, resulting in higher resolution, noise-free data. Although the bulk of the AGASPIII data remains to be analyzed, the enhanced data quality, along with current ground-based calibration studies, will improve our ability to accurately determine important parameters that affect the global climate.

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Tracer Studies in the Stratosphere

J. Vedder

Minor constituents play an important role in upper atmospheric photochemistry and serve as tracers in transport and mixing studies in tropospheric-stratospheric exchange processes. Measurements of trace gases are essential to an understanding of the mechanisms by which minor constituents originating in the troposphere, both naturally occurring and anthropogenic, reach the stratosphere. Data on tracer distributions thus acquired are important in developing models for predicting photochemical effects in the stratosphere.

The work reported here is a joint effort of Ames Research Center and the National Center for Atmospheric Research.

Air collected in stainless steel canisters by the automated whole-air sampler on the ER-2 aircraft and the manually operated sampler on the DC-8 is analyzed by gas chromatography. The whole-air samplers used during the Airborne Antarctic Ozone Experiment were again carried aboard the ER-2 and the DC-8 during the Airborne Arctic Stratospheric Expedition based in Stavanger, Norway, December 1988 to February 1989. The mixing ratios for eight trace gases (CO_2, CH_4, CO, N_2O, CF_2Cl_2, $CFCl_3$, $C_2F_3Cl_3$, and CH_3CCl_3) were reported in the field. Results of the analyses of the ER-2 samples were often available within 1 day of the return of an ER-2 flight. An additional gas chromatograph was operated at the site to measure other trace species of interest.

The low levels of long-lived trace gases confirmed the expected descent of cold polar stratospheric air at high latitudes. In the troposphere, the increase in the background mixing ratios of CH_4, N_2O, and chlorofluorocarbons over the continent was larger than expected. Upwind from the continent, an increase in the chlorofluorocarbons indicates an arctic wintertime buildup of trace species. This buildup is similar to that found in recent arctic haze studies.

These measurements are important in understanding the photochemistry and dynamics of the atmosphere. The measured mixing ratios of trace gases help to determine the age and origins of air parcels involved in ozone photochemistry. Knowledge of total chlorine and bromine is important in determining the potential for catalytic ozone destruction. Since the major species contributing to the organic chlorine and bromine content of the atmosphere were measured, the distribution and total amount of these two elements in the atmosphere can be derived by including the measurements of inorganic halogens.

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Biospheric Monitoring and Vector-Borne Disease Prediction

B. Wood, K. Hibbard

The World Health Organization reports that the global malaria situation has deteriorated during the past 15 years. Factors influencing this include reduced funding and manpower for control activities, increased resistance of the anopheline vector to insecticides, and development of drug-resistant forms of the plasmodium parasite. Under these conditions, a phased multiyear research program has been designed to determine the feasibility of using remote sensing and related data-handling technologies to identify, monitor, and model the relationship between malaria vectors and their environment.

Rice fields are prime breeding habitats for *Anopheles freeborni*, the western malaria vector, and have been the subject of intensive study for the past 25 years. The density of mosquito breeding in the rice fields has been shown to vary significantly from field to field. Often, a few fields are responsible for a large proportion of the mosquito production.

In 1985, a cooperative NASA/University of California study investigated the possibility of using remotely sensed data to monitor environmental parameters associated with the mosquito breeding habitat. In the results, *Anopheles freeborni* larval abundance appeared to be associated with specific vegetational characteristics of rice fields, and was correlated with spectral data acquired in June. Differences in plant biomass and rice phenology among fields, as monitored with spectral data, indicated that those fields supporting few mosquito larvae tended to develop more slowly than those with many larvae.

This suggested that differences in vegetational characteristics, identified and tracked with remote sensing during early-season rice development, might provide the basis to predict larval mosquito production before its peak in late summer. These results encouraged a more comprehensive study in 1987.

In California's Sacramento Valley, 104 rice fields were surveyed for vegetation development, mosquito production, and distance of high- and low-mosquito-producing fields from cattle pastures between May and September 1987. Of the fields studied, 16 accounted for 85% of the total seasonal mosquito production. It was also determined that 83% of high-mosquito-producing fields were located within 5.0 kilometers of a pasture. Conversely, 63% of low-mosquito-producing fields were located more than 5.0 kilometers from a pasture.

Reflectance data were used to calculate a statistical function (canonical discriminant) to identify fields that were above and below a threshold of 0.09 larvae per dip, averaged over 10 weeks. Results showed that 52 fields were above and 52 fields were below this threshold. In May and June, the accuracy of the discriminant function to identify the high-mosquito-producing fields was between 73 and 81%. The highest accuracy was on May 20, more than 2 months before peak mosquito production.

In 1986, the Pan American Health Organization reported more than 950,000 cases of malaria in the Americas. This represented the continuation of an upward trend during the past 30 years. Of the 21 Latin American countries reporting active malaria-control programs, Mexico ranked second only to Brazil in total malaria cases. In Mexico, the number of cases rose by more than 50% between 1984 and 1986.

Work has been initiated on the second phase of this research in Chiapas, Mexico, where malaria transmission is a serious problem. In Chiapas, two mosquito species are responsible for malaria transmission: *A. albimanus* in the coastal plain and *A. pseudopunctipennis* in the foothills.

During the dry season, *A. albimanus*, the principal vector of malaria, is generally found below 200 meters elevation in association with floating vegetation in permanent bodies of water and along streams and rivers. In the wet season it extends its range into rainwater grassland pools. *A. pseudopunctipennis* is found above 200 meters, and during the dry season it is found in association with algae in drying stream beds. Increased runoff during the wet season destroys much of the habitat for this species.

Preliminary analysis of Landsat Thematic Mapper data, acquired during the wet and dry seasons, indicates that the data can be used to characterize and monitor temporal and spatial changes in breeding habitat. Data on breeding habitats subsequently will be integrated with data on meteorology, hydrology, land use, and settlement patterns to develop a model to predict areas of potential malaria transmission.

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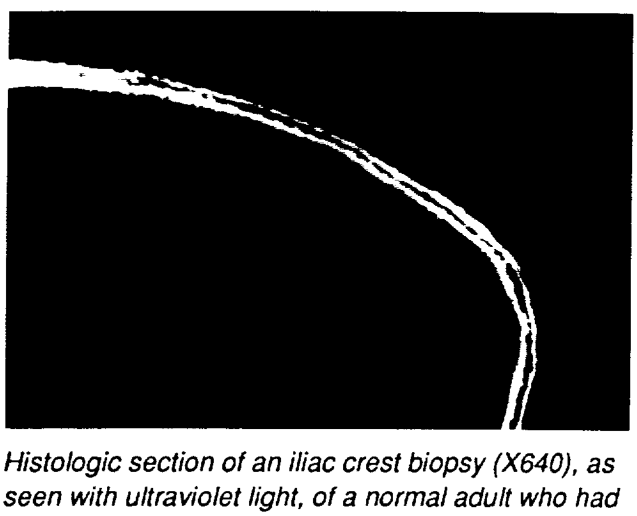
Bone Response to a 7-Day Bed Rest Model for Spaceflight

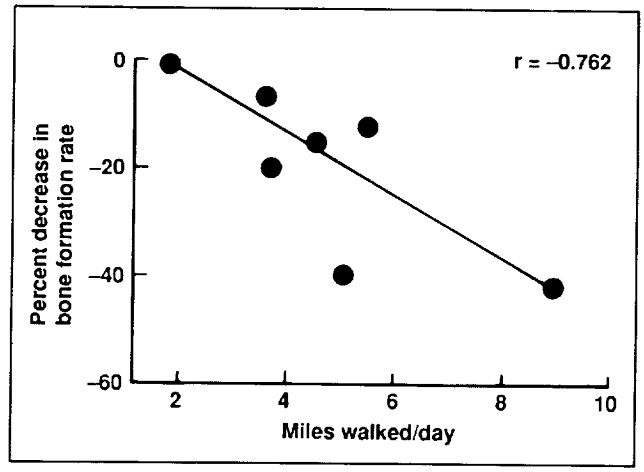
S. Arnaud

It is firmly established that the formation of bone in young rats is reduced in space. How the skeletons of healthy adults will respond to the weightless environment remains uncertain. A pilot study for a flight project directed at determining the early response in bone mineralization in men was carried out in a bed rest model of spaceflight. Eight volunteers agreed to have small pieces of bone tissue removed from the hip bone after 7 days bed rest, by a biopsy technique that is commonly used in medical practice for diagnosing metabolic bone diseases.

One novel aspect of the bone study was the manner in which time markers were used to quantify the rates of bone mineralization during the 3 weeks preceding the study. Dr. D. Sherrard, from the Veterans' Administration Hospital in Seattle, Washington, developed a single-dose schedule for giving the time markers. These markers are tetracycline antibiotics that are laid down on the surfaces of bone matrix at the site of calcification. Their fluorescent property enables the morphologist to identify both the surfaces where bone mineral is being deposited at the time the antibiotic is given and the amount of matrix made in bone in the interval between doses (illustrated in the first figure for a two-dose schedule).



Histologic section of an iliac crest biopsy (X640), as seen with ultraviolet light, of a normal adult who had taken a single dose of tetracycline followed by a single dose of Declomycin after 7 days. The fluorescent lines mark the 2 days of medication at the calcification front in trabecular bond (from Sherrard and Maloney, Amer. J. Clin. Path. 91:682, 1989)



The relationship between the number of miles walked daily before bed rest and the percent decrease in bone formation in the iliac crest after 7 days of bed rest in healthy adult men

A three-dose schedule was used in this study to mark the amount of new bone formed during 1 week of activity and 1 week of bed rest. After only 1 week of bed rest, reduced bone mineralization was demonstrable in six of the eight subjects. The rate of formation was too low in one to detect any change, and one subject showed an increase in the bone-formation rate.

A second novel aspect of the study was the quantification of each subject's activity level by history and pedometer readings that could be related to bone morphology, determined from a bone just above the major load-bearing joint of the body. As illustrated in the second figure, we found the greatest decrease in bone-formation rates in the iliac crest of subjects who walked the most miles daily, during the week before bed rest, and the preceding year.

The study shows not only the rapid response of the adult skeleton to changes in biomechanical forces, but also the importance of activity level on that response.

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Fluorocarbon Polymer Surfaces Exposed to Atomic Oxygen

M. Golub, T. Wydeven

Polymeric films or coatings are known to undergo surface recession, or weight loss, at various rates when exposed on the Space Shuttle to atomic oxygen, the principal atmospheric constituent in low Earth orbit (LEO). As part of a mechanistic study of this film erosion or degradation, electron spectroscopy for chemical analysis (ESCA) studies were performed on the surface oxidation of a series of fluorocarbon polymer films exposed to oxygen atoms either on the STS-8 Space Shuttle or within or downstream from a radio-frequency oxygen plasma. Particular interest attaches to fluorine-containing polymers since polytetrafluoroethylene (PTFE, or Teflon) is known to be one of the most stable plastics in LEO environment.

The importance of an understanding of the surface erosion, or etching, of polymers subjected to atomic oxygen stems from a need to design or formulate new polymer structures for long-duration service in LEO that are highly resistant to O-atom attack. Although considerable data have been reported on weight-loss measurements in polymer films exposed to O atoms—both in space and in ground-based experiments—scarcely any work has been done on the ESCA examination of such polymers.

The fluorocarbon polymers examined by ESCA, besides Teflon, were poly(vinyl fluoride) (PVF, or Tedlar), poly(vinylidene fluoride) (PVDF, or Kynar), tetrafluoroethylene-hexafluoropropylene copolymer (TFE/HFP, in the form of a Teflon FEP coating on Kapton H, i.e., Kapton F), tetrafluoroethylene-ethylene copolymer (TFE/ET, or Tefzel). Polyethylene (PE), a non-fluorine-containing analogue of Teflon, was included in the study to support data on the effect of fluorine content on O-atom-induced surface oxidation of polyolefins.

ESCA revealed that all these polymers exhibited a dynamic competition between surface recession (etching) and oxidation, such that the etching front maintains a steady-state elemental composition once the maximum level of oxygen uptake is attained. The extent of maximum surface oxidation was found to decrease regularly with an increase in fluorine substitution in the family of ethylene-type polymers, i.e., PE ($-CH_2CH_2-$) > PVF ($-CH_2CHF-$) >TFE/ET ($-CH_2CH_2CF_2CF_2-$) > PVDF ($-CH_2CF_2-$) > PTFE ($-CF_2CF_2-$) or TFE/HFP [$(-CF_2CF_2-)_x(-CF_2CF(CF_3)-)_y$]. This order of maximum surface oxygen uptake does not parallel exactly the corresponding order of etch rates downstream from the glow of an oxygen plasma; however: PVF > PE > PVDF (or TFE/ET) > PTFE (or TFE/HFP). Nor does it reflect the order of etch rates either in the glow of an oxygen plasma or in LEO, where—except for PTFE or TFE/HFP in LEO—there is little dependence of etch rate on polymer structure.

Although considerable information has been obtained concerning etch rates and surface oxidation of various polymers, including the fluorocarbon polymers, much remains to be learned about the mechanisms of oxygen atom reactions with various polymers.

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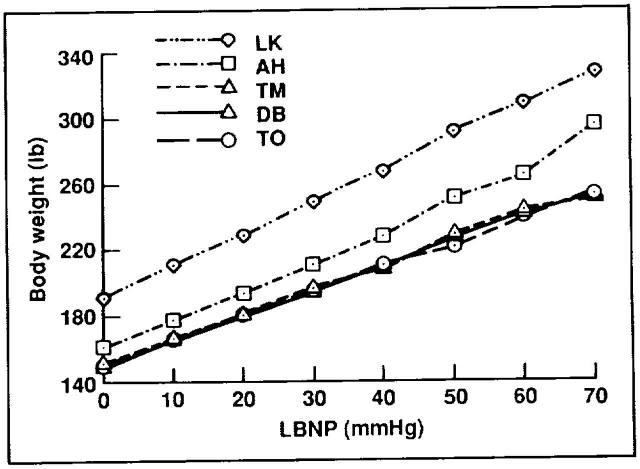
Exercise Hardware for Long-Duration Spaceflight

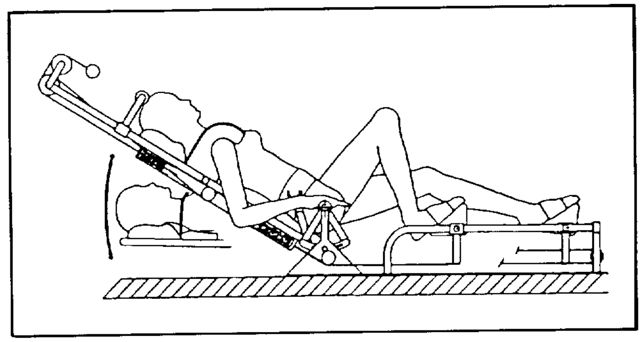
A. Hargens, D. Schwandt, R. Whalen, S. Parazynski, D. Watenpaugh

A variable resistance exercise device is needed to maintain muscle and bone as well as cardiovascular fitness during long-term exposure to microgravity. Furthermore, based upon a mathematical model that predicts how bone density will vary with loading history, it may be possible to maintain musculoskeletal mass in space by safely imposing higher forces than those applied by existing flight hardware.

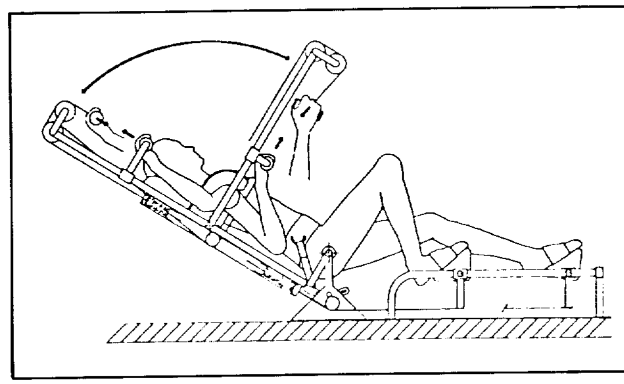
Advantages of our exercise technology concepts include (1) minimal exercise time is needed for maintaining musculoskeletal fitness; (2) reduced rehabilitation time after extended-duration missions; (3) performance quantification (i.e., force/torque, speed, power, endurance, cardiovascular and fitness level) for direct feedback to crew member; (4) data acquisition and analysis for training protocols and ground-based research; (5) vibration isolation for certain



Increase in body weight as a function of lower-body negative pressure



ERGOSPACE design, highlighting aspects of the lower-body exercises built within the device



ERGOSPACE design, highlighting aspects of the upper-body exercises built within the device

configurations to minimize adverse effects of shock on material science experiments; (6) compactness and light weight; (7) accommodation for stretching and aerobic ergometry; and (8) use of lower-body negative pressure (LBNP) in one concept as a means to load the postural musculoskeletal system and to rehydrate interstitial spaces of the lower body.

Historically, LBNP has been used as a cardiovascular challenge to translocate blood to the lower parts of the body. The usual procedure is to increase suction to 30-50 millimeters mercury while the subject lies horizontally against a saddle. We explored LBNP as a potential short-term countermeasure to load the musculoskeletal system of the lower body and as a way to create simulated gravity.

Results indicate that LBNP may be a potent stimulus to load the musculoskeletal system periodically, especially if it is combined with exercise during prolonged space travel (see the first figure). It also appears to be an effective way of generating simulated gravity.

With the ERGOSPACE exercise device, the crew member progresses through a full series of exercises combining concentric and eccentric muscle contractions to load various muscle groups throughout the body (see the second and third figures).

The equipment illustrated in the second figure allows the astronaut to be harnessed onto a backboard so that the forces applied to the lower extremities are absorbed equally by the shoulders and pelvis. The angle about the hip can be changed for leg press exercises, and calf or gastrocnemius-specific exercises. The feet can be externally rotated to enable exercise of the adductor longus muscle. Other options on this fully monitored, spring-driven system are lower-extremity flexion exercises (hamstrings, anterior tibial muscle), back extensions, and abdominal curling exercises.

The equipment illustrated in the third figure allows the astronaut to be stabilized with a torso harness and foot straps while performing a number of different upper extremity exercises off a machine arm that pivots from the backboard: regular and military presses, lateral pull-down, and horizontal pull. Other exercise options include bicep- and tricep-specific exercises, as well as rotator cuff and neck exercises.

The exercise equipment will help promote subject compliance and motivation. This hardware reproduces exercises and simulates equipment found in a weight-training environment on Earth. This research and development represents a multidisciplinary approach combining expertise in physiology, biomechanics, and design at NASA Ames Research Center; Palo Alto Veterans Administration Rehabilitation Research and Development Center; Stanford Center for Design Research; and Sports, Orthopedic and Rehabilitation Medicine Associates.

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Waste Streams in a Crewed Space Habitat

T. Wydeven, M. Golub

Closing the major life support function loops (recycling water and air, growing plants for food, and waste management) on future long-duration, human space missions is vital for realizing significant reductions in launch weight by reducing the need for large quantities of expendables and even eliminating the resupply requirements. To achieve these reductions, NASA's Physical-Chemical Closed Loop Life Support (P/C CLLS) Program aims at identifying and developing critical chemical engineering technologies to enable closure of the air and water loops and to process waste streams within future spacecraft and surface or space habitats.

Space missions contemplated beyond Space Station Freedom are the establishment of a Lunar base and a piloted mission to Mars. Although partial closure of the atmospheric and water loops for the Space Station life support system is now achievable, there is a need to develop fully *regenerative* physical-chemical life support systems for extended human space missions where resupply is not feasible. Such systems should allow for eventual integration of biological subsystems to augment air, water, and waste processing or recycling and to provide for food production, as visualized in a Controlled Ecological Life Support System.

WASTE FEED STREAM PRODUCTION RATES AND SOLIDS CONTENTS IN A CREWED SPACE HABITAT

Stream ID	Wet weight formation rate, kg/person-day	Dry weight formation rate, kg/person-day	Weight, percent solids
Toilet waste			
Urine	2.11, 1.50, 1.39, 1.27	0.059	3.9, 4.1
Feces	0.0955, 0.132	0.0205, 0.03, 0.021	21.4, 15.9
Toilet paper		0.0051, 0.0411	
Urinal flush water	0.494		
Pads/tampons		0.0035	
Menstrual solids		0.0004	
Hygiene water			
Laundry water	12.5		0.023
Clothes and towels		0.0007	
Crew		0.0014	
Cleansing agent		0.0007, 0.025	
Shower/hand wash water	5.4, 5.5		0.060, 0.097, 0.13
Crew		0.0017	
Cleansing agent		0.0016, 0.0085	
Dish wash water	5.4		0.022
Cleansing agent		0.0012	
Trash	0.816, 1.00, 1.49, 1.62		72.7, 64.7
Humidity condensate	0.52		
Perspiration and respiration	1.82, 2.50	0.016, 0.02	0.65, 1.05
Metabolic CO_2		1.00	
Trace contaminants in cabin air		Shown elsewhere	

One element of the P/C CLLS Program involves waste management. A current Ames Research Center task specifically addresses the subelement of "waste composition definitions"; that is, a needed compilation of available information on sources, generation rates, and chemical compositions of various waste streams emanating from humans and equipment in a closed environment in space. Clearly, the selecting, monitoring, and sizing of suitable processes for recycling air, water, and other essentials in space (either in a spacecraft or on a planetary surface) require such information concerning the waste streams that are to be processed in a P/C CLLS system. The information is also crucial to developing simulation models of waste treatment scenarios. The importance of computerized simulations for chemical processing systems applied to advanced P/C CLLS technologies was recently emphasized.

A further role for waste stream definitions is to identify those streams that may be toxic or hazardous. Toxic wastes, besides being harmful to humans, may also be toxic to microorganisms, thereby preventing the use of a biological waste treatment method for disposing of such wastes.

The table presents a compilation from various literature sources of the data considered best representative of the major human-derived waste feed streams in a closed space environment. This information is to be incorporated into the Ames P/C CLLS data base and used by NASA scientists and engineers for modeling and developing advanced regenerative life support systems for future space missions.

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Growth Hormone Concentration and Distribution in Plants

R. Berthold

The Growth Hormone Concentration and Distribution (GHCD) experiment flown on STS-34 from October 13-23, 1989, is based on the hypothesis that the concentration and distribution of the plant growth hormone, indoleacetic acid (IAA), will be affected by microgravity. To study the effects of zero gravity on the distribution of IAA, the experiment required that plant seedlings (*Zeamays*, or corn) be grown in complete darkness in zero gravity.

At the John F. Kennedy Space Center Hangar L Pre-Flight (Space Life Science Payloads Office Pre-Flight Facility), the seeds were prepared in a hood for placement into the flight canisters. No unusual or dangerous chemicals were used for this procedure. During preflight activities, the passive liquid nitrogen (GN_2) freezer was also prepared for flight. This involved a NASA procedure that has been used on previous Shuttle flights. The GN_2 freezer was charged with several liters of liquid nitrogen under strict safety guidelines and then decanted.

The plants were grown from seeds inside four hollow stainless steel canisters planted 18 hours before flight. During flight, the plants grew for 4 days; two canisters were placed inside the gaseous nitrogen freezer to arrest plant growth and preserve the IAA inside the plant tissue. Two other plant canisters remained untouched for a postflight analysis of continued growth. A detailed analysis of IAA concentration and distribution in the plant will be made on frozen samples.

Postflight, the frozen canisters were placed in a dry ice (frozen carbon dioxide) shipper that was sent to the principal investigator's lab.

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Cosmos Project

J. Connolly

More than 85 NASA-sponsored researchers from 19 states and 3 foreign countries participated in 29 cooperative investigations on Cosmos 2044, a biosatellite mission flown by the Soviet Union September 15-29, 1989.

Cooperative investigations on the 14-day Cosmos 2044 Mission addressed questions related to the biomedical effects of prolonged spaceflight. Biological specimens on this unpiloted, recoverable spacecraft included rhesus monkeys, rats, fish, fish eggs, newts, drosophila, beetles, seeds, unicellular organisms, and planaria. Investigations covered bone and muscle alterations, circadian rhythms and thermoregulation, neurophysiology, radiation measurements, and gravitational biology.

Nearly 3,000 biological samples from Cosmos 2044's flight and control groups of subjects were returned to laboratories across the United States for analysis. Many of the cooperative U.S.-U.S.S.R. investigations on this mission have expanded upon investigations flown on previous Cosmos missions. Cosmos 2044 is the seventh Soviet biosatellite mission in which NASA has participated.

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Mid-Infrared Photon Counting Detector (MIP Code)

J. Goebel

Many fields of science and technology could be advanced if researchers were able to detect single mid-infrared photons in their experimental apparatus. At Ames Research Center, we have developed an instrument capable of single photon detection based upon the recently invented solid state photomultiplier announced by Rockwell International Science Center scientists Petroff, Stapelbroek, and Kleinhans. The detector is capable of forming 30,000 electrons per photon in the wavelength range 2 to 28 micrometers. This capability allows scientists to achieve the fundamental detection limit, and can improve the sensitivity of current low-background instrumentation by a factor of 100 to 1000. Single atomic transitions in the infrared can now be observed, a capability heretofore unknown.

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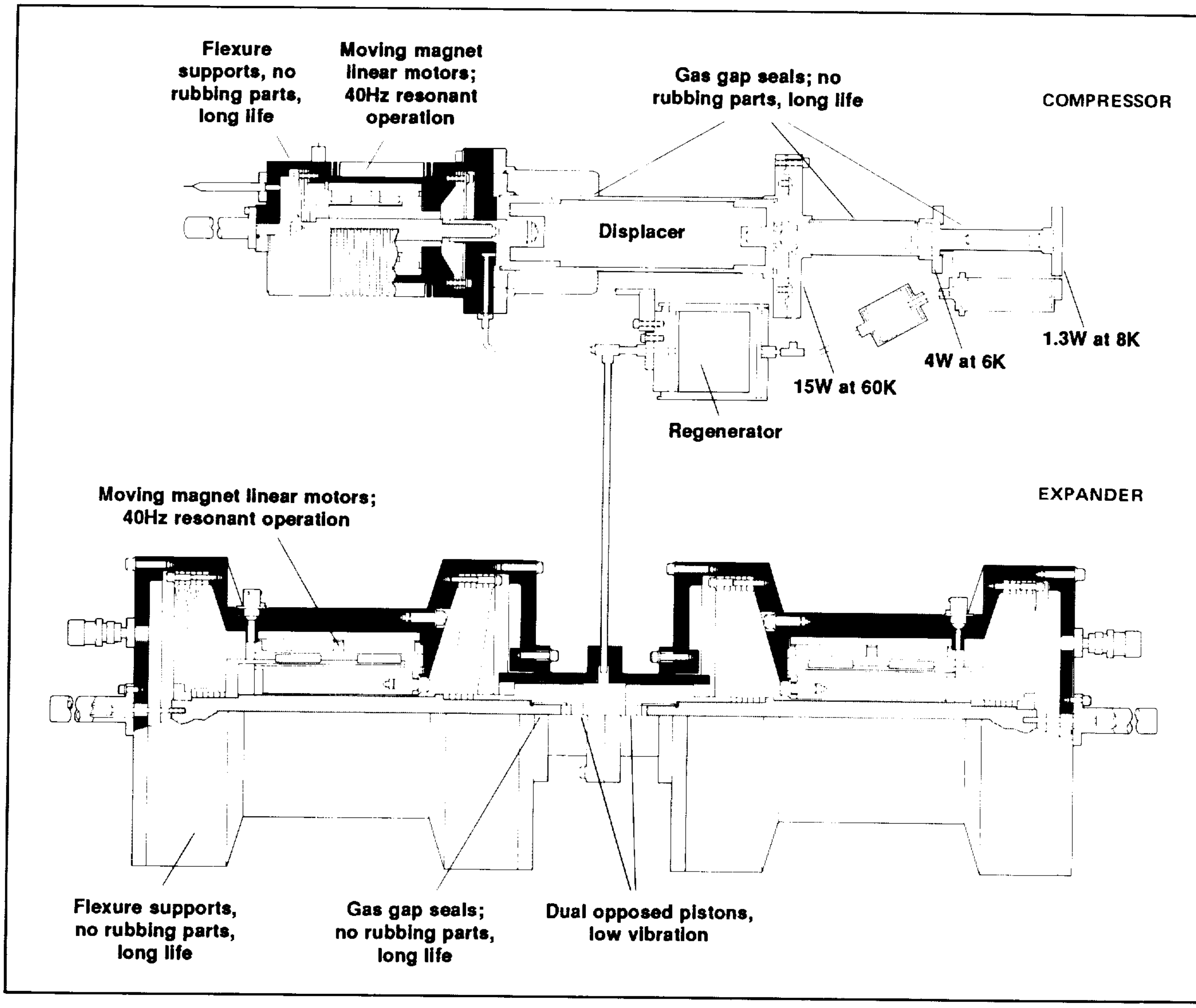
Three-Stage Stirling Cooler for Space Applications

P. Kittel

A novel cryocooler for long-lived space applications has been designed by APD Cryogenics, Allentown, Pennsylvania. The cooler is intended for use as either a shield cooler in stored cryogen systems or as a pre-cooler for a 2 Kelvin cooling stage. In the formal application it would be used to intercept the parasitic heat load in the stored liquid helium system, thus reducing liquid boil-off. This would extend the system lifetime or allow the use of a smaller cryogen tank to achieve the same lifetime. In either case the total system mass for a given lifetime would be reduced.

In the latter application, the cooler would absorb the heat rejected by the magnetic cooling stage. This combined cooler would be used in place of stored liquid helium, thus reducing the mass and volume of the overall system. The latter cooler is aimed at the Large Deployable Reflector mission and is being developed as part of the OAST Science Sensor Technology Program.

While this cooler draws on previously built coolers, it has several novel features. These features, along with a general layout of the cooler, are shown in the figure. The cooler uses the linear split Stirling cycle, which allows the compressor and expander sections to be separated on the spacecraft. Long life is achieved by eliminating all rubbing parts, so there are no parts to wear out. Narrow gas gaps are used as clearance seals and flexures are used as bearings.



Configuration of the three-stage Stirling cooler showing the principal features

While much of this technology has been used previously in small, single-stage coolers (such as the Improved Stratospheric and Mesospheric Sounder cooler on the Upper Atmospheric Research Satellite), this cooler advances the technology by an order of magnitude. It is more than an order of magnitude more powerful, and, by using three stages of cooling, it will reach almost an order of magnitude lower temperature. The predicted cooling power is 15 Watts at 60 Kelvin, 4 Watts at 16 Kelvin, and 1.3 Watts at 8 Kelvin with 750 Watts input at 300 Kelvin. The low temperature of the third stage is lower than that achieved by existing Stirling coolers. This is made possible by the use of a novel regenerator made from a lead and stainless steel composite.

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Low-Background and Radiation Environment Testing of Infrared Detector Arrays

M. McKelvey

During FY 1989, further investigations of the performance characteristics of 58- by 62-element direct readout (DRO) extrinsic silicon infrared (IR) detector arrays were performed. This array technology, developed by Hughes Aircraft Co., has been adopted as the baseline for the Infrared Array Camera of the Space Infrared Telescope Facility (SIRTF). Testing in FY 1989 concentrated on characterization of the Si:Sb array in a radiation environment simulating that experienced in Earth orbit.

Laboratory characterization of this array type has been previously conducted in our laboratory, determining basic performance levels with an eye toward the use of these devices in orbiting observatories. In the earlier work we demonstrated that these sensors can be used for low-background infrared astronomical imaging with extremely high sensitivity, and we also identified areas where the technology needs further development.

In FY 1989 the effort moved to the complex problem of learning how the ionizing particles found in Earth orbit modify the performance levels measured in earlier tests. Radiation-environment testing was emphasized to assess the suitability of this array technology for use on platforms at altitudes up to 100,000 kilometers.

Small (millicurie) sources of gamma- and x-radiation have been used in the Ames Research Center IR Detector Lab to simulate the on-orbit environment, in terms of both radiation field and low IR background. In addition, a proton-environment test program began in FY 1989 using the 74-inch cyclotron at the Davis campus of the University of California. Dose rates at the Davis facility can be varied over a wide range to simulate the majority of anticipated on-orbit ionizing particle fluxes. The devices have shown substantial sensitivity to proton fluxes, with significant shifts in their radiometric calibration after irradiation. We have also found methods which can be used to recover the pre-irradiation performance characteristics. We are concentrating on identifying the determining mechanisms and parameters of the observed radiation effects with the goal of controlling and minimizing them.

A cooperative effort between NASA's Ames Research Center and Goddard Space Flight Center is under way for the Ames Si:Sb array to make pioneering IR astronomical observations, using an integrated detector array at a wavelength of 20 micrometers. The array will be used at NASA's Infrared Telescope Facility for imaging observations of the apparent disk of material surrounding the star Beta Pictorus. In addition to the astronomical data to be obtained, this demonstration will help us better understand the strengths and limitations of the device.

Additional research will allow a final judgment to be made on the suitability of this technology for SIRTF and other orbiting IR telescope platforms. Behavior of the Si:Sb devices in the on-orbit radiation environment and comparative studies of alternative detector technologies (for example, impurity band conduction detectors) are two areas where the continuing test effort will be concentrated in FY 1990.

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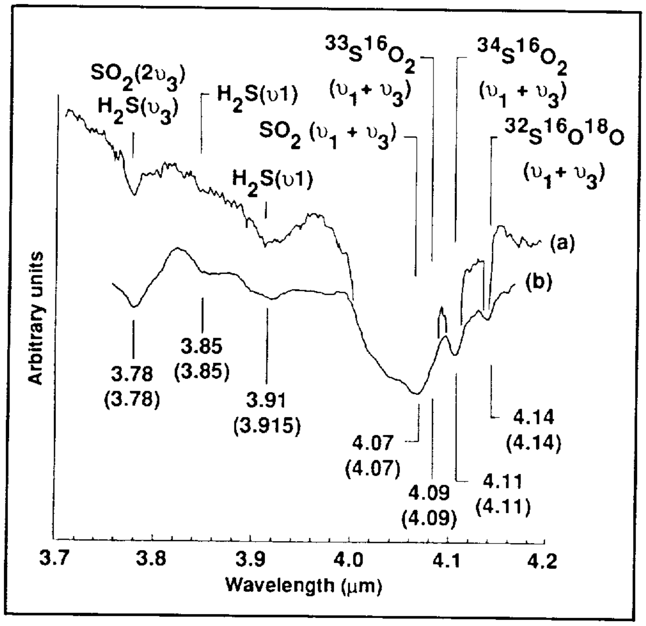
Highlights of Research in the Laboratory Astrophysics Group

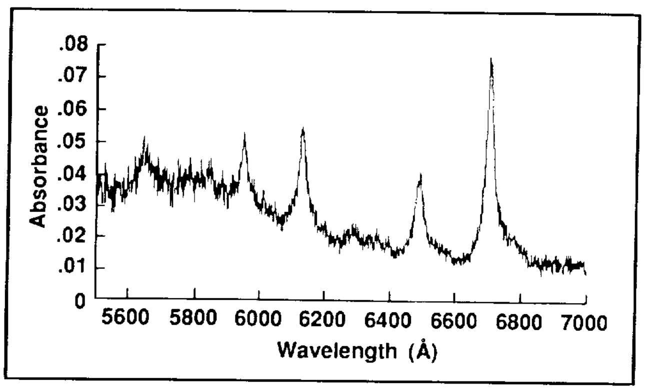
L. Allamandola, F. Salama, S. Sandford

During 1989, the Laboratory Astrophysics Group at Ames Research Center made substantial progress in several areas. One area involves the preparation of frozen gases believed to be representative of ices in the solar system. The infrared spectra of these ices are compared to the spectra of planets and their moons to ascertain the celestial bodies' composition.

After an extensive set of laboratory experiments we showed that the spectrum of Io, the volcanic moon of Jupiter, can be matched only if the SO_2 ices



Comparison between (a) the infrared spectrum of an $H_2S:SO_2$ ice (3:100) at 100 Kelvin and (b) the reflectance of Io showing that H_2S is present



Preliminary absorption spectrum of the naphthalene cation ($C_{10}H_8^+$) isolated in an argon matrix at 4.2 Kelvin

known to be present contain appreciable quantities of H_2O and H_2S as well (see the first figure). Besides showing, for the first time, that Io contains H_2O and H_2S, this work shows that Io contains significant amounts of hydrogen, a fact which gives important insight into the evolutionary history of this peculiar moon.

We also completed the installation of a new cryogenic spectroscopy laboratory. The equipment in the laboratory allows measurement of the ultraviolet, visible, and infrared spectroscopic properties that materials possess at temperatures a few degrees above absolute zero. By using this laboratory, the visible spectrum of the isolated aromatic naphthalene ion (see the second figure) and its thermoluminescent emission were measured for the first time.

These early results are extremely significant because they demonstrate that we can isolate and study the spectral properties of aromatic hydrocarbon ions in the new laboratory. The study of the spectral properties of ionized aromatic hydrocarbons is important because it has been postulated that between 30-50% of the infrared radiation from the galaxy is carried by these species and very little is known about them.

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Isotopic Ratio Measurements Using a Diode Laser Spectrometer

J. Becker, T. Sauke

The development of semiconductor laser technology has progressed to the point where tunable diode lasers can be realistically considered for a reliable, lightweight, high resolution molecular spectrometer, suitable for flight hardware. Such a spectrometer can be used as a gas detector, but will have the capability to measure stable isotopic ratios without the problem of interference from impurity gases.

We completed our study of the pressure broadening of the $^{12}CO_2$ P(37) and $^{13}CO_2$ R(28) spectral lines. At pressures above approximately 1 Torr, the width of spectral lines increases owing to collisions between molecules in the excited state and other gas molecules in the sample. From our data we calculated the optical collision cross section which characterizes the extent of this interaction.

The experimental data were fit to the Voigt profile using the well-accepted approximation in which the complex error function is replaced by a sixth-order-rational fraction, the real part of which is the Voigt function.

OPTICAL COLLISION CROSS-SECTION VALUES CALCULATED FROM SPECTRAL LINE-BROADENING COEFFICIENTS (m)

	m	$[DCO_2\text{-}N_2]^2$	$[DCO_2\text{-}CO_2]^2$
$^{12}CO_2$ P(37)	0.067 cm^{-1} atm^{-1}	5.09(10)$^{-14}$ cm^2	24.5(10)$^{-14}$ cm^2
$^{13}CO_2$ R(28)	0.072 cm^{-1} atm^{-1}	5.40(10)$^{-14}$ cm^2	24.1(10)$^{-14}$ cm^2

From experimentally determined spectral line-broadening coefficients (m), optical collision cross-section values were calculated (see table).

Temperature, as well as pressure, affect the width of spectral lines. We have installed a temperature-controlled cell in our laser spectrometer, which can be used to study line widths as a function of temperature in the 300-500 K range. Preliminary experimental results on low-pressure Doppler broadened lines indicate the line widths increase as $\sqrt{T}$, as expected from kinetic theory.

High-precision isotopic ratio measurements require extensive digital signal averaging, as well as the elimination of as many sources of systematic error as possible. By developing optimized assembly language subroutines, we have dramatically increased the data signal averaging speed and versatility. Also, several sources of systematic error in the measurements have been identified, namely sampling/sweep synchronization jitter, non-flat preamplifier gain response owing to A.C. coupling, temperature drift of cooled laser diode, and pump vibrations from the diode cooling system. Strategies have been formulated and at least partially implemented to characterize, take into account, or eliminate each of these sources of systematic error.

In collaboration with Max Loewenstein of Ames Research Center, a new infrared tunable diode laser spectrometer system using multiple beams and the new generation of higher temperature diodes has been designed and is on order.

This equipment can be used to measure isotopic ratios of other elements. Especially interesting is $^{14}N/^{15}N$, because this ratio may be useful in dating Martian samples. The nitrogen isotopic ratio on Mars is significantly different from that on Earth, and it has been suggested that this ratio may have changed on Mars over the life of the planet, thus providing a means to date Martian samples.

Furthermore, in addition to characterizing planetary samples, such as rocks and minerals on Earth and on Mars, tunable diode laser spectroscopy has the potential of providing a technique to measure nondestructively the pressure and temperature of gases in such laboratory applications as plasmas, shock tubes, and wind tunnels.

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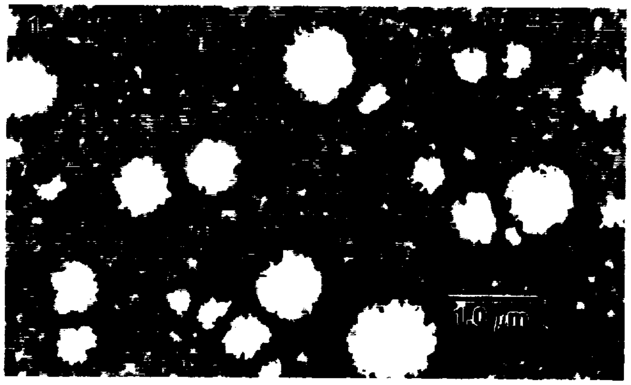
Analysis of Cometary and Interstellar Ice Analogs

D. Blake, L. Allamandola

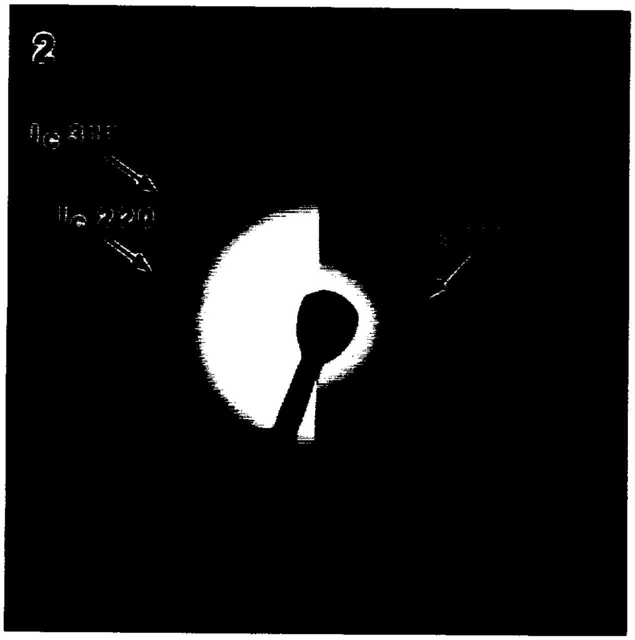
Many astrophysical objects are composed of ices or ice-rock mixtures. The most important of these are comets, the outer satellites and planets of our solar system, and cold molecular clouds which are the birthplace of stars and planetary systems. There is much interest in studying these objects because they contain relatively pristine, unprocessed materials which may yield clues to the origin of our solar system and of the materials antecedent to the origin of life. Astrophysical ices are studied remotely by Infrared Astronomy which can be used to deduce their bulk chemistry and average structure. In the laboratory, infrared spectra are recorded from synthetic ices and these spectra can be compared in detail to those recorded from astrophysical ices.

We have completed extensive modifications to an Analytical Electron Microscope (AEM) so it can nondestructively analyze analogs of cometary and interstellar ices. It is now possible to determine the microstructure and microchemistry of ices grown inside the microscope at temperatures from 273 Kelvin (0°C) to 110 Kelvin (−163°C). We are mixing gases of water, methane, ammonia, carbon dioxide and monoxide, methanol, and the like, and freezing them directly on the microscope stage to determine what phases and stability relationships exist at these extremely low temperatures.

The first figure shows pure water ice nucleated from a gas onto a substrate at 130 Kelvin. The ice crystals, which appear as dark angular grains in the figure, are randomly oriented and range in size from 0.01 to 0.1 micrometer.



Transmission electron microscope micrograph of water ice crystals grown on an amorphous carbon substrate at −140°C (130 K). The scale bar is 1.0 micrometer



Transmission electron diffraction pattern from a small area of the first figure. The pattern corresponds to the cubic form of ice, stable from −140 to −100°C. The bright rings corresponding to the {111}, {220}, and {311} diffraction directions in cubic ice are labeled

The second figure shows an electron diffraction pattern from the ice which can be used to determine its crystal structure. The pattern corresponds to the cubic form of ice which is stable between 130-170 Kelvin. By adding various compounds (such as those listed above) which are known to be present in astrophysical ices, the changes in stability relationships can be determined.

This research provides microstructural and microchemical data which can ultimately be used to interpret infrared observations of astrophysical objects. The expertise gained in growing, processing, handling, and analyzing low-temperature ices will be useful for a variety of proposed or funded NASA flight missions including Comet Rendezvous and Asteroid Flyby, Galileo, Rosetta (Comet Nucleus Sample Return), and Mars Sample Return.

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Particle-Gas Dynamics in the Protoplanetary Nebula

J. Cuzzi

During the last decade, theoretical and observational studies have demonstrated the likelihood that flattened disks of dust and gas will form as a natural by-product of stellar formation, and have established their global thermal and dynamical properties. Collisional accretion of comet-sized planetesimals leads to the growth of solid planetary cores, followed by hydrodynamical accretion of nebula gas to form Jovian-type planets in the outer solar system. However, poorly understood stages connect these landmark events, and earlier stages of accretion are even less well understood. For instance, accretion of the planets has long been thought to result from the particulates settling into a sufficiently flattened layer for gravitational instability to occur. However, gas drag and turbulent shear in and around the particle layer may result in diffusional spreading of the particle layer and prevent gravitational instability.

We developed a detailed numerical model of the early nebula environment, which adequately treats the processes occurring in a medium containing two distinct phases (gas and particles) which obey different forcing functions, but are coupled by aerodynamic drag and are therefore able to influence each other's dynamical properties.

During 1989, we completed development of two turbulence models: (1) a Prandtl-type with gas eddy viscosity proportional to the local shear, and (2) a two-equation model which solves transport equations for the turbulence. Results of these two models agree very well. In addition, we developed a simple model of the nondimensional "Schmidt Number," which depends on the fluctuation timescales of the turbulence and the "stopping time" of the particles (a function of their mass and size).

We found that diffusive expansion of the particle layer, preventing gravitational instability, indeed, continues until the particle sizes are considerably larger than previously expected. That is, we can show that particles must accrete to sizes approaching planetesimals themselves (tens to hundreds of meters, depending on their density) before they can become gravitationally unstable. We also demonstrate in detail for the first time the dynamics and mean motion of the gas and particle phases. A radial outward flow is set up in the gas in the vicinity of the particle layer, and an associated inward drift of the particle phase, caused by momentum transfer between the particle layer and the intermingled gas.

These results have major implications for our understanding of the fine structure we can observe in the meteorite record.

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Planetary Ring Dynamics and Morphology

J. Cuzzi

Planetary rings as a class share many structural similarities, and presumably similar controlling processes. Obviously, there are great differences in detailed structure between the broad, opaque rings of Saturn; the nearly transparent rings of Jupiter; the dark, narrow rings of Uranus; and the incomplete ring arcs of Neptune. On the other hand, these systems are similar in their combinations of diffuse rings of material interspersed with belts or ensembles of mountain-sized "moonlets." We hope to understand these similarities and differences in terms of the conditions of formation and the operation of similar processes in different environments.

Following the Voyager encounters with Jupiter (1977), Saturn (1980-81), Uranus (1986), and recently Neptune, our understanding of ring structure has been greatly enhanced. From an understanding of the structure and dynamics of planetary rings, we hope to gain insight into the process by which planets form from their own protoplanetary particle disks. In several of the projects described, faculty and student collaborators from Stanford University, Indiana University, and the University of Arizona have played important roles.

During 1989, considerable activity was devoted to planning, executing, and attempting to understand the results from the Voyager encounter with Neptune. The presence of incomplete clumps of material or "ring arcs" orbiting Neptune has been known since 1986, but has remained controversial. The Voyager sequence was planned to be a complete and systematic study of the inner Neptune region, and to take advantage of the variation of observing geometry to determine the distribution of rings and ring arcs, as well as to find examples of small moonlets in the region.

A major question was whether the arcs were transient features, being created and dispersed on decade timescales, or whether some dynamical process kept them stably confined in their limited ranges of longitude. The fading solar illumination and diminishing data rate at Neptune required extremely long exposures, as well as close-in sequences to be targeted at the last moment once the arcs had been discovered.

The encounter was very successful. A complex and well-developed ring-moon system was discovered (orders of magnitude more substantial than that of Jupiter) complete with three ring arcs. Careful comparison of the Voyager observations with ground-based stellar occultations in 1984 and 1985 has revealed that the three arcs seen by Voyager have been stable at least over this time span, and that they are not merely transient clumps of debris. However, the only two "confinement" theories proposed before the encounter, unfortunately, have been ruled out because of the lack of sufficiently massive confining objects in appropriate locations. Work on these topics continues.

Our group continues to play a leading role in analysis and interpretation of the structure and composition of planetary rings. During 1989, we completed a major study for the Cassini project concerning the distribution of faint material surrounding the main rings of Saturn. The efforts of several groups were combined in using spacecraft and ground-based remote-sensing observations of ring brightness, along with in situ observations of magnetospheric depletion by orbiting material too low in density to see directly. The study pointed to several optimum radial regions where the spacecraft could cross the ring plane with minimum risk.

In addition, the properties of Saturn's E and G rings were much more strongly constrained than previously. The E ring has a very peculiar particle-size distribution, entirely dominated by a very narrow range of micrometer-sized particles. The reason for this is unknown, but these tiny particles must be replenished, probably from the geologically young-looking satellite Enceladus, on a time scale of decades or centuries.

We are modeling the process by which material gets redistributed within ring systems following meteoroid bombardment. The coupled transport of mass and angular momentum, combined with the normal viscous processes acting in particle disks, can result in complex and nonintuitive structures such as small-scale fluctuations, systematic buildup, or erosion of material near certain kinds of edges, and other structures similar in many ways to features observed in the rings. This modeling is a major numerical effort, as it needs to account for the angular and velocity distribution of the ejected material in a realistic way. Current work focuses on inner ring edges.

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Biospheric Change Recorded in Ancient Organic Matter

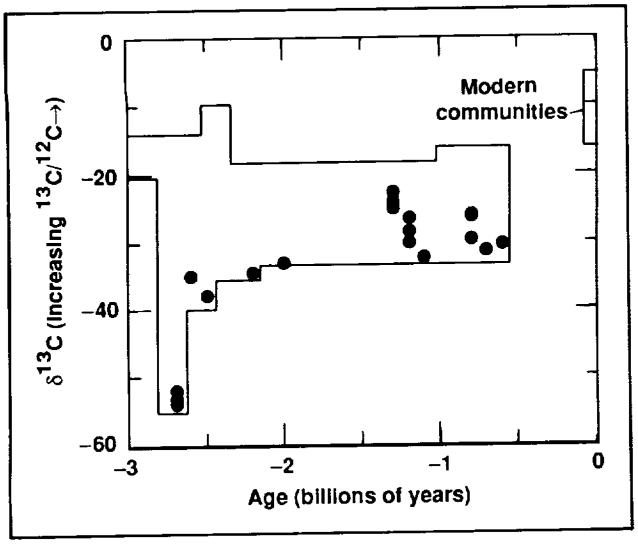
D. DesMarais, S. Cronin

Although most of the organic remains of marine life is quickly degraded or used by other organisms, a small fraction escapes into sediments and is buried and preserved in rocks. This "rock record" of organic remains is 3.5 billion years old and has recorded certain aspects of our biosphere's development.

Unfortunately the ravages of time and elevated temperatures have altered much of this sedimentary record and have erased biological information as the organic matter is slowly converted to graphite. Fortunately, geochemists have learned how to recognize relatively well-preserved organic matter, and they have also found that its biological synthesis imposes a stable carbon isotopic "signal" which is remarkably resistant to thermal destruction. This signal reflects principally both the isotopic selectivity of those enzymes which assimilate inorganic carbon and the rate at which this carbon is assimilated, relative to its abundance in the environment.

Our group analyzed organic matter from 2.5 to 0.6 billion years old. We collaborated with the Precambrian Paleobiology Research Group–Proterozoic, which was organized by Dr. J. W. Schopf of the University of California, Los Angeles, to study Precambrian rocks (older than 0.57 million years) of Proterozoic age (between 2.5 and 0.57 million years old). Our Ames Research Center group examined stromatolites, which are fossil microbial communities that constructed laminated rocks typically made of limestone or silica.

Our results are summarized in a plot of carbon isotopic composition of the organic matter versus its age (see figure). Higher $^{13}C/^{12}C$ values plot toward the top of the figure. All the analyses fell within the region depicted by the solid line. Most of the organic samples were so modified by thermal alteration, as evidenced by their low hydrogen contents, that their carbon isotopic compositions were no longer reliable



Carbon isotopic content of organic matter versus its age. Solid line encloses all data; circles depict data which accurately reflect original biological information

indicators of the original biological activity. However, those analyses represented by the filled circles in the figure *are* reliable, because they correspond to sufficiently well-preserved samples.

These reliable analyses depict a long-term trend of increasing $^{13}C/^{12}C$ values. This long-term $^{13}C/^{12}C$ trend likely reflects the biosphere's adaptation to declining levels of carbon dioxide in the oceans and atmosphere. The $^{13}C/^{12}C$ values measured in organic matter older than 1.5 billion years are typically produced by contemporary photosynthetic organisms growing with an unlimited supply of carbon dioxide. Thus it is not necessary to postulate that the carbon-fixing enzymes have changed radically during the past 2 billion years. However, as the availability of carbon dioxide declined, enzymatic discrimination against ^{13}C diminished, and the $^{13}C/^{12}C$ value of the organic matter which is produced increased. Thus, this long-term isotopic trend likely reflects the adaptation of photosynthetic organisms to a decline of carbon dioxide levels by a factor of at least 10 to 100. We are now challenged to understand how such an important environmental trend has influenced the course of biological evolution.

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Space Infrared Telescope Facility Moves Into High Earth Orbit

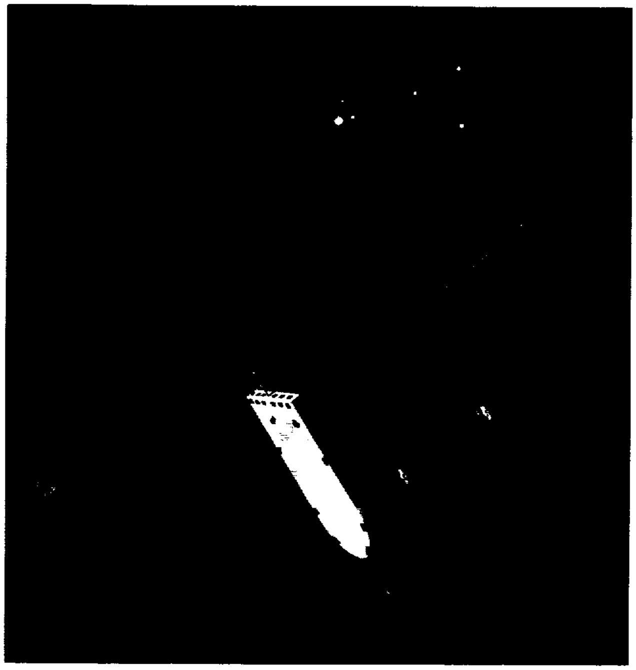
P. Eisenhardt, M. Werner

On March 24, 1989, NASA Associate Administrator for Space Science and Applications, Lennard Fisk, approved a new high Earth orbit (HEO) for the Space Infrared Telescope Facility (SIRTF). Current plans set SIRTF's launch in 1998. The new orbit was selected following a study led by Ames Research Center, which considered alternative missions which would achieve SIRTF's science objectives. Orbits considered ranged from a 900-kilometer altitude, low inclination circular orbit (the previous baseline), to the Earth-Sun L2 Lagrangian point (1.5 million kilometers in the antisolar direction).

SIRTF's fundamental goal is to make infrared observations with sensitivity limited only by the naturally occurring backgrounds present outside of the Earth's atmosphere. These backgrounds are over a million times lower than those seen by a ground-based infrared telescope, resulting in more than a thousand-fold gain in sensitivity. To achieve this sensitivity, SIRTF's optics (including the 95-centimeter diameter primary mirror), instruments, and baffles will be cooled by liquid helium. The helium supply will allow a minimum mission lifetime of 5 years, most of which will be used by general observers.

The long lifetime is essential to SIRTF's role as one of NASA's Great Observatories, a family which includes the Hubble Space Telescope, the Gamma Ray Observatory, and the Advanced X-Ray Astrophysics Facility. SIRTF will also be the first cryogenic space telescope to take full advantage of the new generation of infrared detector arrays. Three instruments, selected in 1984, will observe from 2 to 700 micrometers: a Multiband Imaging Photometer (Principal Investigator (PI) George Rieke, Arizona), an Infrared Spectrograph (PI Jim Houck, Cornell University), and an Infrared Array Camera (PI Giovanni Fazio, Center for Astrophysics).

The HEO mission will use a Titan IV/Centaur to launch SIRTF into a 100,000-kilometer altitude orbit. (A halo orbit about the Earth-Sun L2 LaGrangian point is an option for this class of mission still under study.) This altitude places SIRTF outside the Van Allen belts, whose trapped energetic particles would



Artist's conception of the Space Infrared Telescope Facility in the newly selected high Earth orbit. Note the apparent small size of the Earth, the fixed solar array, and the diminutive aperture shade

degrade instrument performance. Power is supplied by rigidly fixed solar panels, and omnidirectional antennae provide communications between the observatory and the 26-meter dishes of NASA's Deep Space Network.

The angular size of the Earth seen from HEO is less than 7°. This makes the Earth a minor contributor to the thermal load on SIRTF, allowing a predicted outer shell temperature of 110 Kelvin and a helium supply lifetime of 6 years. The Earth's small angular size in HEO also permits high on-target efficiency (estimated at 90%), continuous observation times for a single target of 50 hours or more, and viewing of 14 to 33% of the sky at any one time, depending on the relative position of the Sun, Earth, and spacecraft. In addition, over one hundred square degrees around each orbital pole are continuously viewable in HEO for 6 months at a time.

The long on-target times and good sky accessibility in HEO will greatly simplify the scheduling process. Long wavelength performance (beyond 100 micrometers) will be excellent in HEO because of the low, stable telescope temperatures achieved (less than 4 Kelvin for all helium-cooled components).

The unanimous conclusion of the SIRTF Study Office at Ames, the other NASA centers studying SIRTF options, and the SIRTF Science Working Group, is that HEO offers significant scientific and engineering advantages for SIRTF. NASA's adoption of an orbit which enhances the scientific productivity of the mission, together with the dramatic advances in infrared array detectors, promise to make SIRTF an extraordinarily effective and versatile instrument for studying a broad range of astrophysical problems.

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Stratospheric Observatory for Infrared Astronomy

E. Erickson, J. Davidson

For the past quarter century Ames Research Center has conducted a program of astronomy from aircraft. This program demonstrated that an airborne observatory operating in the lower stratosphere can provide routine access to infrared wavelengths unavailable from the ground, and provide the means to observe transient astronomical events from anywhere in the world.

The major facility in this program has been the Kuiper Airborne Observatory (KAO), a 0.9-meter telescope in a Lockheed C-141 aircraft, which has provided roughly 75 observing flight opportunities each year since 1975 for astronomers from the United States and foreign institutions. The broad spectral regime available from the operating altitude of 41,000 feet encompasses a multitude of rich and varied physical processes, allowing scientists who use the KAO to collect an impressive variety of important astronomical results.

A Stratospheric Observatory for Infrared Astronomy (SOFIA) with a 2.5-meter telescope in a Boeing 747, is planned to replace the KAO in 1995.

It would achieve about 10 times more sensitivity and 3 times more angular resolution than the KAO. Planning includes 120 observing missions each year and support of about 15 instrument and 25 guest investigator teams, selected by annual peer review of submitted proposals. The Federal Republic of Germany would collaborate in both the development and the operation of SOFIA at about the 20% level, in return for a comparable fraction of the flight time for its science community.

Questions to be addressed by airborne astronomers using SOFIA include: What is the structure, composition, and chemistry of planetary atmospheres? How do protoplanetary disks form and evolve? How are bipolar outflows and disk formation involved in starbirth processes? Is there a black hole at our Galactic Center? How do stars form in different types of galaxies? What fuels star bursts and active galactic nuclei?

During 1989, definition studies of the telescope system in Germany and on the aircraft system in the United States have been concluded. A number of technical issues have been addressed regarding the design and performance of SOFIA. Some of these are science requirements, air-flow control concepts, aircraft structural modifications, atmospheric transmission, background emission, turbulence levels affecting pointing, star tracking, seeing, optical image quality, optics configuration, structural stiffness, angular stabilization range, mirror coatings, and telescope design. These and other studies have resulted in a feasible design concept which meets the basic scientific needs for the astronomical community. The next step will be detailed design and fabrication, which will proceed if funding from both the United States and Germany is made available.

Much of the universe's radiation lies at infrared wavelengths which are not observable from ground-based telescopes. SOFIA will provide ready and frequent access to these wavelengths with a combination of spatial and spectral resolution which will be unmatched for decades. The airborne astronomy tradition of annual opportunities for initiating new science and instrumentation, a powerful stimulus for young researchers, would be continued by SOFIA. The United States established world leadership in infrared science through detector technology, the Infrared Astronomy Satellite flow in 1983, and the KAO. If developed as planned, SOFIA will help sustain this leadership throughout the next 25 years.

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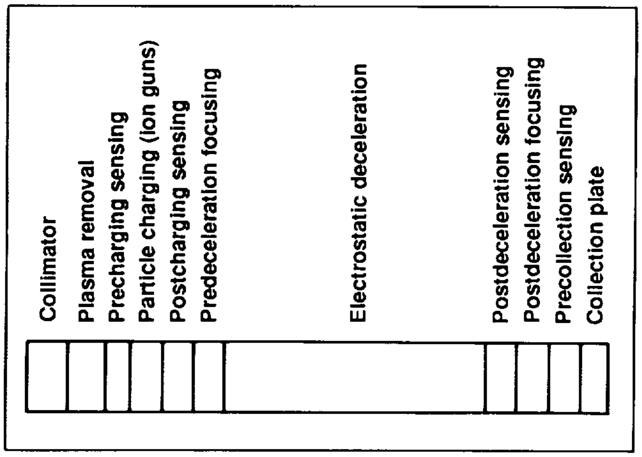
Active Technique for Space-Based Cosmic Dust Collection

G. Fogleman, J. Huntington, G. Carle

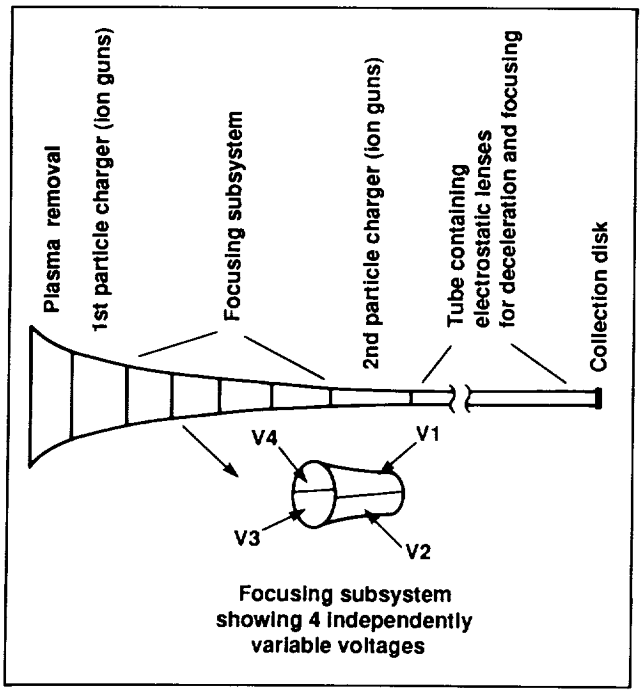
Cosmic dust is expected to represent material from asteroids, comets, meteorites, and interstellar dust. Collection and analysis of unaltered cosmic dust particles and the elements and compounds contained therein would provide new and important information to exobiologists and planetary scientists. In particular, this information would advance our understanding of the role played in chemical evolution by the biogenic elements (C, H, N, O, P, S) and related compounds that accumulated in the solar nebula and accreted onto the planets.

Cosmic dust particles are thought to have brought important biogenic elements and compounds to the early Earth and so may have played an important role in the origin and evolution of life. An instrument for collecting cosmic dust particles intact and for accurately identifying the captured dust's parent body would represent a powerful tool for the exobiological and planetary sciences.

The concept for such an instrument, the Active Collector of Cosmic Dust (ACCD), is being developed at Ames Research Center under support from NASA Headquarter's Life Sciences Division. As an attached payload on the post-assembly phase of Space Station Freedom, the ACCD would be designed to capture cosmic dust particles intact and uncontaminated for exobiological analysis. It would collect cosmic dust particles several micrometers in radius and with relative velocities up to 25 kilometers/second. As cosmic dust particles enter the instrument, trajectory sensors would



Active Collector of Cosmic Dust design concept A



Active Collector of Cosmic Dust design concept B

measure their trajectories with sufficient precision to identify their source regions. Then the particles would be charged with ion guns, decelerated electrostatically, and collected on plates or in underdense media. Collected particles would be returned to Earth for analysis.

Two analytical studies of the ACCD have been performed and two conceptual designs have been produced (see schematics of concepts A and B). A proposal, "Concept Study to Develop an Active Collector of Cosmic Dust," submitted in response to the NASA Announcement of Opportunity for Space Station Freedom Attached Payloads, has been selected for funding.

The proposed work consists of a 3-year study to develop the ACCD concept. The concept study has been divided into three major tasks: (1) an experimental study of the particle-charging efficiency of ion guns; (2) an engineering study of ionospheric plasma removal and ion gun subsystem designs, and an overall systems study of the two ACCD conceptual designs; and (3) an engineering study of particle detection, particle velocity, mass and charge measurement, particle focusing, and particle deceleration. This concept study has been structured so a competitive and complete ACCD flight instrument proposal for Space Station Freedom can be produced at the end of the study.

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Small-Particle Research on Space Station Freedom

G. Fogleman, J. Huntington, G. Carle

A wide range of fundamental scientific problems involving interactions between small (micrometer-sized) particles could be addressed by conducting particle experiments in the low gravity (microgravity) environment of Space Station Freedom. Examples of such experiments suggested by scientists at Ames Research Center include the following:

1. Particle-aggregation studies relevant to hypotheses concerning phenomena such as nuclear winter, species extinction due to climatic changes, effects of volcanic eruptions, and the duration of Martian dust storms.
2. Investigations of the synthesis of amino acids (as well as other complex organic compounds necessary for the origin of life) on the surfaces of growing particles.
3. Determination of the growth, optical properties, and chemical composition of the organic aerosols

produced in Titan's atmosphere by simulating the organic haze production in Titan's atmosphere.

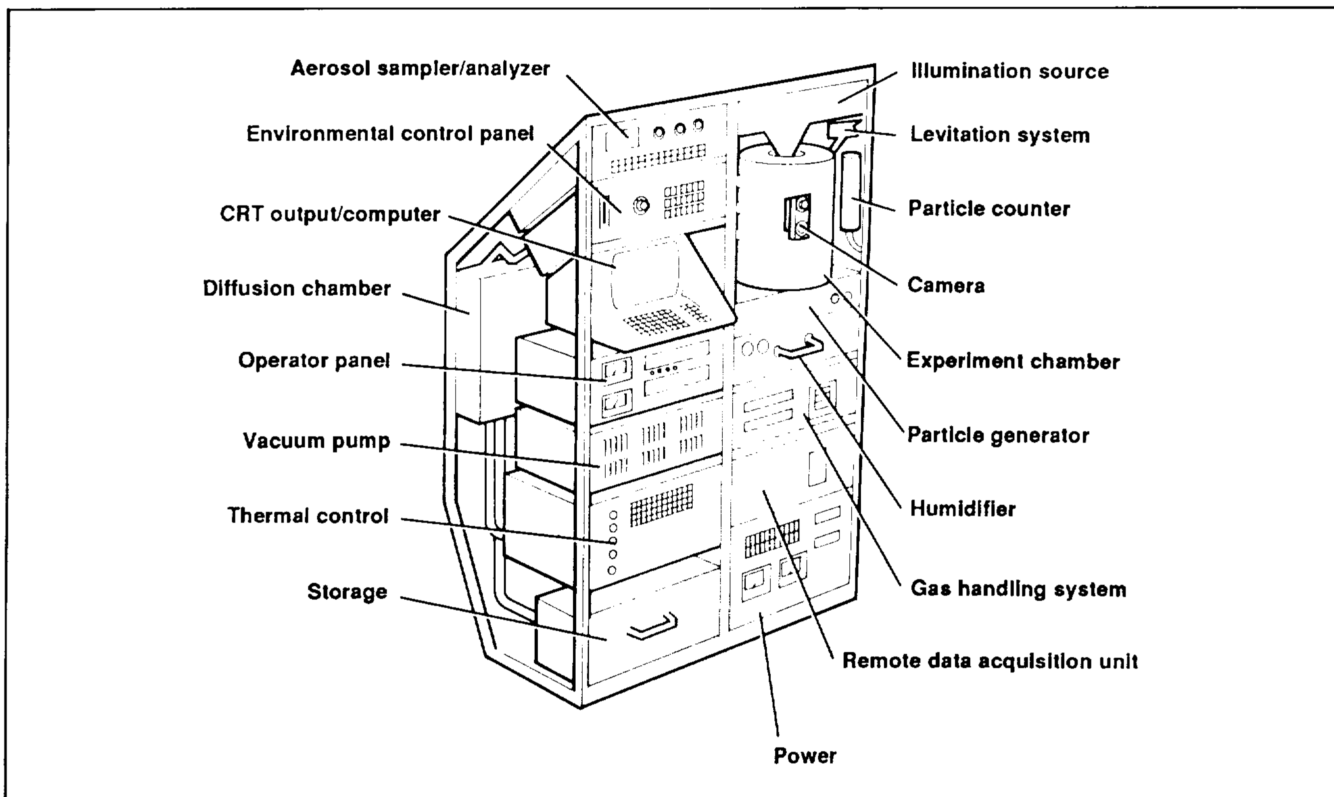
4. Studies of dipolar grain coagulation and orientation as a possible mechanism for polarizing starlight shining through interstellar and intergalactic dust clouds.

5. Simulation of radiative emission by particles in various astrophysical environments such as circumstellar shells, planetary nebulae, and protostellar disks.

Microgravity particle experiments have also been suggested by other NASA and university scientists representing such diverse disciplines as exobiology, planetary science, astrophysics, atmospheric science, and basic physics and chemistry. The suggested experiments have in common the requirement that they be performed in an extremely low gravity ($<10^{-4}$ m/sec^2) environment. In many cases the microgravity environment is required because the experiments (1) must suspend aggregates for times substantially longer than possible in ground-based laboratories, (2) require a convection-free environment, or (3) propose to grow and study fragile aggregates that are gravitationally unstable in the gravity environment on Earth.

Ames is developing an interdisciplinary research facility, the Gas-Grain Simulation Facility (GGSF) (see the figure), for conducting small-particle research in the microgravity environment of Space Station Freedom. Development of this facility is sponsored jointly by the Life Sciences Division and the Solar System Exploration Division at NASA Headquarters.

The GGSF is specifically designed to facilitate experiments that simulate and study, in a microgravity environment, fundamental chemical and physical processes involving particles in the sub-micron to millimeter size-range. Processes such as nucleation, growth, coagulation, condensation, and low-velocity collisions will be studied with this facility. The GGSF will occupy a 1 cubic meter volume and will provide the following: a 15-liter experiment chamber; environment control subsystems (e.g., temperature,



Gas-grain simulation facility

pressure, gas mixture, and humidity); mechanisms for particle production, positioning, and removal; measurement equipment (e.g., video cameras, optical particle counters, spectrometers, and photometers); and energy sources.

Ames conducted two workshops to determine the scientific requirements of the GGSF. These workshops led to the establishment of an interdisciplinary science community interested in GGSF microgravity particle research and resulted in the development of a data base of candidate GGSF experiments. Theoretical and computer calculations have been performed to analyze the candidate experiments and to refine the GGSF science requirements. In-house engineering studies have been conducted, leading to a conceptual design and cost estimate of the facility. A result of these activities is the inclusion of the GGSF in the Headquarter's Life Sciences' Space Biology Initiative and in the OSSA utilization plan for Space Station Freedom.

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Minerals as a Source of Oxygen in Planetary Oxidation and Their Possible Link to the Origin of Life

F. Freund, S. Chang, T. Wydeven

The early history of the Earth is shrouded in mystery. The geological record indicates that, in the beginning, our planet was in a highly reduced chemical state but became ever more oxidized as billions of years passed. What is the source of this oxidation power?

Oxygen can be left in the atmosphere when hydrogen is lost to space by photodissociation of water vapor in the upper atmosphere. Though this process still occurs today, the amount of oxygen produced is insufficient to account for Earth's oxygen. Alternatively, it has been postulated that oxygen was produced by early lifeforms which developed the complex biochemical apparatus to transform H_2O and CO_2 into organic matter plus oxygen through photosynthesis. This process maintains the present oxygen level in the atmosphere.

We have predicted an unexpected source of oxidation power in minerals that crystallize deep in the Earth's crust in the presence of H_2O and CO_2 gases and fluids. The minerals take up traces of H_2O and CO_2 and dissolve them in their structures. In the process a redox reaction takes place which splits a portion of the H_2O and CO_2 into H_2 plus elemental C while the oxygen enters the mineral structure in the form of peroxy entities.

There are two ways to determine the occurrence of this unusual reaction: (1) by identifying the traces of H_2 plus elemental C which are hidden in the mineral structure, and (2) by establishing the presence of peroxy entities.

We have achieved a major breakthrough by providing for the first time the proof that minerals, both synthetic and natural, contain peroxy though they have crystallized under highly reducing conditions in the presence of H_2O and CO_2. The peroxy entities were identified by measuring the dielectric and magnetic susceptibility of minerals over a temperature interval in which the peroxy entities decompose into highly mobile, paramagnetic species, so-called positive holes. Part of the progress is due to the development of a new physical technique, Charge Distribution Analysis (CDA), which allows detection of mobile charge carriers. With the unambiguous identification of positive holes in minerals, the presence of peroxy entities is confirmed.

Consequences of this new development may be far-reaching. Peroxy in minerals constitutes a huge reservoir of oxidation power. During mountain building, after tectonic and volcanic forces transport rocks from great depth to the surface of the Earth, the minerals decompose by weathering. Some of the resulting sedimentary rocks are subducted in tectonic processes. Large quantities of rock are thus recycled—today as much as 3 cubic kilometers/year. During the weathering process, peroxy converts into hydrogen peroxide, a powerful oxidant. Reduced carbon and H_2 molecules are liberated from the minerals at the same time, possibly in the form of abiogenically formed organic matter.

Though our data base is still very limited and quantitative values for peroxy contents in common minerals are not yet available, we can roughly estimate the oxygen from such a source. If the average peroxy content in common minerals is about 40 parts per million—a conservative value—and if the yearly rate of weathering of rocks in the early part of the Earth's history was 10 cubic kilometers, the amount of hydrogen peroxide and, hence, of oxygen injected into the geological cycle would be of the order of 10^{11} grams/year or 10^{20} grams in 1 billion years. This corresponds within a factor of 10 to the amount of oxygen required to carry out the massive oxidation of iron laid down in worldwide iron ore deposits 1.5-3 billion years ago. Thus peroxy entities in minerals could have been a significant source of oxygen early on.

Mars will be an important testing ground for the role that peroxy may have played in planetary oxidation. The Martian surface bears signs of a high degree of oxidation, while the average Martian rock composition, which resembles that of a terrestrial basalt, suggests a high degree of reduction. We think that it is possible to design a remote-control CDA instrument that could be sent to Mars to test the Martian soil for its peroxy content.

With the progress made on the peroxy research front, we are now in a much better position to return to the equally or even more exciting search for reduced carbon and possibly abiogenically formed organic molecules in minerals. This line of investigation holds the promise of unveiling some of the mysteries of the origin of life. Earliest life depended upon the availability of complex organic molecules from which the first reproductive chain evolved. Innocuous minerals that contain traces of dissolved H_2O and CO_2 may have provided the matrix in which such complex organic molecules were able to form.

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The C_2 Ballik-Ramsay Transitions in Carbon Stars

D. Goorvitch

The study of carbon stars plays an important role in understanding the evolution of our galaxy. Carbon stars are undoubtedly an important source of interstellar carbon. The interiors of stars are also laboratories for studying the nuclear reactions which play a critical role in the evolution and death of stars. From the reprocessed stellar material comes the atomic elements that make up our universe.

Since the photosphere is the boundary interface of a star between its interior and the interstellar medium, an understanding of the physical state of this boundary layer is important for studies involving the interstellar medium, the abundance of the elements, and the interior of the star.

Recently, high resolution interferometers have obtained high quality (i.e., high signal-to-noise) spectra useful for probing the outer photospheres of carbon stars. The spectra obtained in the near infrared are rich in spectral features. These observed spectral features contain a wealth of information about a star. Analysis of these spectral features will result in identifying the emitting species, finding their distribution, and understanding their physical environment. However, the observed spectral features have been significantly modified by their environment.

Deducing the chemical and physical environment is directly proportional to our knowledge of how the isolated sources emit radiation. Only very precise information about the way molecules in the photosphere emit will suffice. A very important species radiating in the near infrared region of the spectrum is C_2.

I have written a computer algorithm for calculating highly accurate transition parameters for the Ballik-Ramsay band of C_2, including all the satellite lines. The combination of spin-orbit coupling and lambda doubling in the lower triplet pi state gives rise to 27 branches (9 main, and 18 satellite branches). Adding to the complexity of these 27 branches are the isotopic variations due to $^{12}C_2$, $^{13}C_2$, and $^{12}C^{13}C$. The Ballik-Ramsay band is then expected to be extremely rich in transitions.

Because the spectral features are formed in stellar atmospheres at temperatures typically between 1000 and 4000 Kelvin, it is important to calculate the line positions and strengths of the transitions for high vibrational (v) and rotational (J) states. Calculation of the transitions in the relatively weaker satellite bands is important for two additional reasons. First, these lines contribute to the underlying stellar continuum. Second, if the line list does not include the weakest lines in a system, the effective microturbulence will have to be chosen somewhat higher to compensate for the missing lines.

Calculation of line parameters for states with high v and J usually entails extrapolating molecular parameters derived from an analysis using fits to data from relatively low values of v and J. Extrapolation is risky and can lead to large errors. To obtain accurate transition parameters, a realistic physical description of the molecular system is necessary. Therefore, I have chosen as a physically realistic description a hamiltonian in full matrix form with the Honl-London factors calculated in the same representation as the hamiltonian, Hund's case a.

A further convenience of the matrix formulation is that perturbing nearby states can be included with relative ease, leading to a more realistic formulation for the band system. I have included the perturbation of the upper triplet sigma state by a close-lying singlet sigma state. This calculation for the Ballik-Ramsay band involves the diagonalization of a 4×4 energy matrix for the upper triplet sigma state and two 3×3 energy matrices for the lower triplet pi state. A line list of approximately 3750 transitions has been calculated for use in synthesizing stellar spectra in the spectral region from 3900 to 4000 cm^{-1}.

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Microbial Origins of Molecular Fossils

L. Jahnke, R. Summons

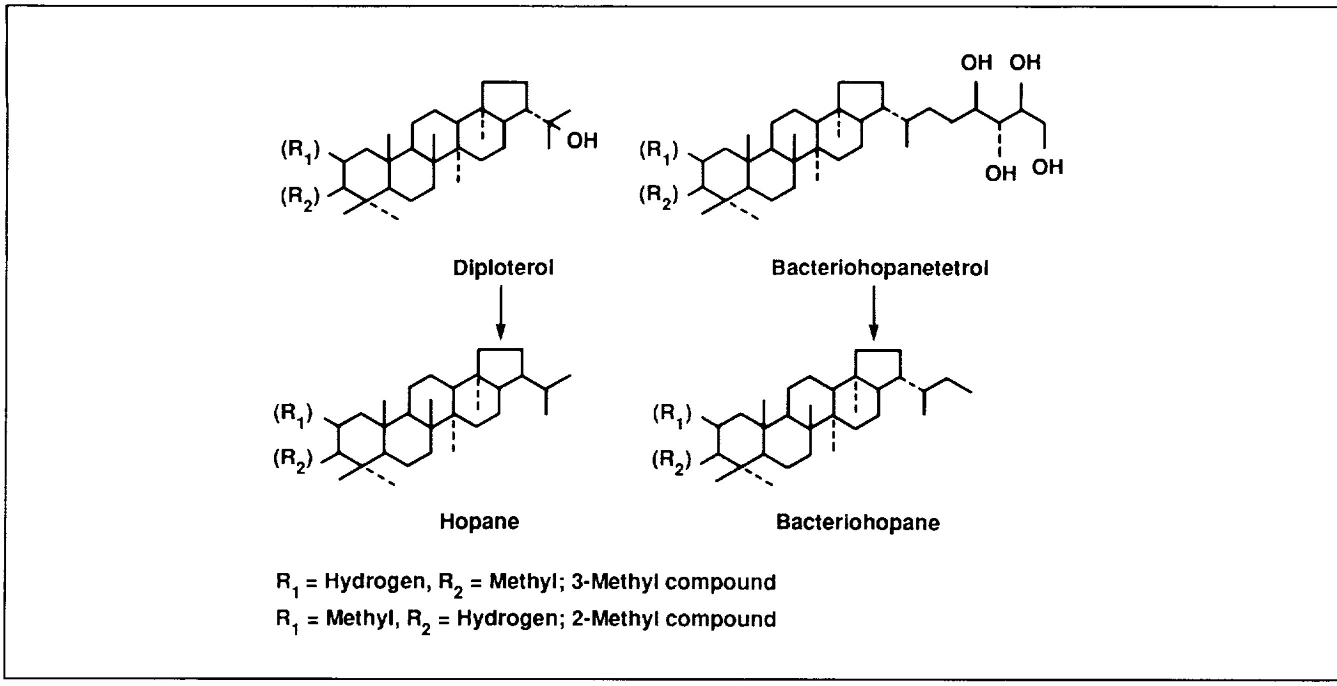
The organic extract of a sedimentary rock is a complex heterogeneous mixture of hundreds or even thousands of compounds. Many of these complex molecules are derived from the lipidic constituents of microbial membranes and are characteristic of specific groups of microorganisms. As such, they are termed biomarkers.

Even when these molecules can be separated in the laboratory, they are not always easily identified and, in many cases, the biological source of the compound is unknown. This was true for one major class of geochemical fossils, the hopanoids. Although these compounds are ubiquitous constituents of sediments and have been identified in rocks as old as 1.5 billion years, their bacterial origins have been discovered only recently.

The hopanoids are particularly important in understanding biological evolution because their molecular structure is similar to the sterols, which are crucial for membrane integrity in the more highly evolved eukaryotes (organisms with nucleated cells). However, while both types of molecule are thought to perform a similar membrane function, there is an important difference in the mechanisms required for their biosynthesis. The synthesis of a sterol is an aerobic process requiring the incorporation of molecular oxygen, while synthesis of a hopane occurs anaerobically.

The synthesis of these biomarkers reflects the historical transition from Earth's anaerobic biosphere to one rich in free oxygen. Their presence in ancient sedimentary rock can help shed light on this evolutionary transition if we can identify the specific source organisms for these molecules and then relate the information to environmental conditions and the chronology of events preserved in the geological record.

Recently, much progress has been made in understanding the importance of geohopanoids to the interpretation of this planet's biological record. Central to this understanding is a group of bacteria, the methanotrophs, which grow aerobically by the



Molecular structures of hopanoids occurring in methanotrophic bacteria and the primary degradation products

oxidation of methane. After the evolution of oxygenic photosynthesis within the cyanobacteria, the evolution of methanotrophs resulted in the first oxidative recycling of carbon and a permanent geochemical record surviving in ancient sedimentary rock.

Methanotrophs synthesize a variety of hopanoids. These compounds are complex, pentacyclic molecules (see the figure) and several methanotrophic ones are unique, having an additional methyl group attached at the 2- or 3-position of the first ring.

In nature, the process of sedimentary maturation results in degradation of these molecules to a variety of seemingly unrelated products which makes interpretation of ancient sediments difficult. We have isolated a number of methanotrophic hopanes and have subjected them to a sequence of chemical reactions designed to simulate the degradation they might have undergone during burial in a sediment. Using gas chromatography-mass spectrometry, we have compared the products with the organic compounds extracted from a 500-million-year-old Ordovician rock and identified a similar series of molecules.

These findings establish for the first time the presence of a group of highly specialized oxygen-requiring bacteria, the methanotrophs, within a specific habitat 0.5 billion years ago. Further work relating the lipid constituents of these and other bacteria to their molecular fossils may develop group signatures and provide additional insight into primitive Earth ecosystems.

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Do Simple RNA-Type Molecules Exhibit Self-Regulating Capabilities?

A. Kanavarioti, S. Chang, C. Bernasconi

In examining models for the chemical origins of life, attention has focused on the synthesis of RNA-type molecules (polynucleotides) and on the capabilities of these molecules to catalyze various reactions as well as to serve as templates for replicating RNA molecules. An important characteristic which model chemical precursors of living systems must share with actual biochemical systems is the capability to self-regulate reactions involving synthesis or degradation of their molecular constituents.

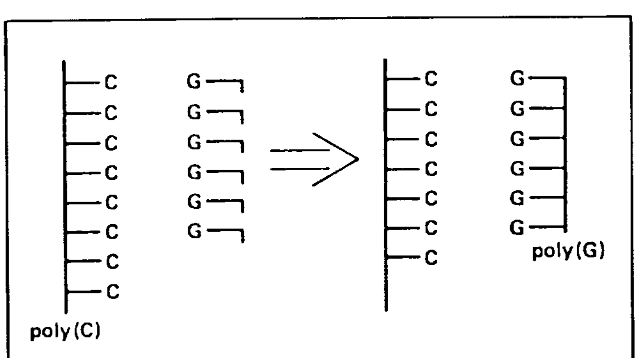
Collaborating scientists from Ames Research Center and the University of California at Santa Cruz are elucidating the mechanism of nonenzymatic, template-directed synthesis of RNA-type molecules from chemically activated mononucleotides and are determining the conditions under which these systems could function. Specifically, we have been studying the polymerization reaction of a mononucleotide (the phosphoimidazolide activated guanylic acid, so-called ImpG, represented as G- in the first figure) on a polynucleotide template, poly(C), to form the complementary polynucleotide strands, poly(G), in lengths containing up to 40 units. This synthesis represents the first half of a two-stage molecular replication cycle: the complement of poly(G) would be the original poly(C).

This model system is interesting because it represents the most efficient polynucleotide synthesis found thus far to occur in the absence of enzymes. Under plausible prebiological environmental conditions, however, ImpG is easily converted to a side-product, the dimeric guanylic derivative, GppG.

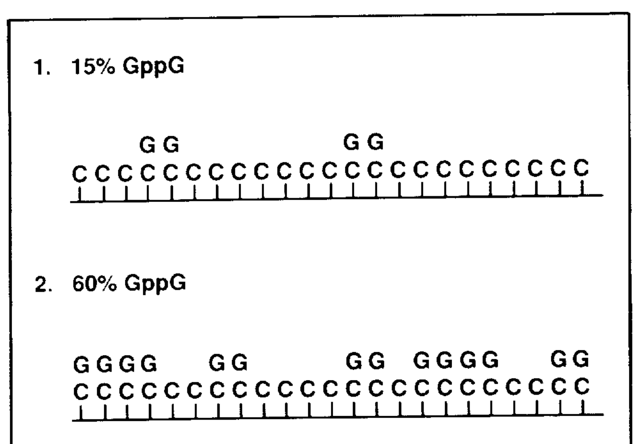
Kinetic studies performed in the presence and absence of GppG indicate that the template-directed polymerization reaction of ImpG is strongly inhibited by the presence of GppG. Apparently GppG occupies some of the sites on the template as a result of Watson-Crick base-pairing in a random fashion between GppG and the C moieties of the template (see the second figure). Thus, partial blocking of the template by GppG decreases the number of available sites for ImpG polymerization, which limits the reaction to the formation of short poly(G) strands.

The experimentally observed slowdown of the overall polymerization in the presence of GppG can be understood as the result of GppG preventing the synthesis of longer strands. In addition, as a consequence of reducing the rate of polymerization, degradation of the monomer by water competes more effectively against its reaction on the template, thereby making less of it available for polymerization. This study leads to the conclusion that the model system is limited by the formation of substantial amounts of the GppG side-product.

On the other hand, the inhibiting role of GppG has additional significance. The relatively high efficiency of ImpG polymerization contrasts with the much less efficient polymerization of other nucleotides (also used by living systems) tested in the model system. This discrepancy in the efficiencies of



Polymerization reaction of a mononucleotide on a polynucleotide template



Oligoguanylate synthesis inhibited in the presence of GppG the template-directed polymerization among various nucleotides is probably an important factor contributing to the inability thus far to achieve a full replication cycle with these model systems.

The existence of a mechanism that will impede poly(G) synthesis, however, can be viewed as a self-regulating capability of the system, mainly because formation of GppG occurs when there is an excess of ImpG. Without GppG's inhibition effect, in a model system using more than one type of nucleotide (more closely resembling the biochemical system), rapid formation of poly(G) would exclude other nucleotides from incorporation into mixed polynucleotides.

It appears, therefore, that GppG may provide an internal control mechanism much like the feedback mechanism in living systems today, in which excess of product in many enzymatic reactions triggers inhibition of further product formation. These considerations lead one to hypothesize that chemical systems based on nucleic acids may indeed exhibit self-regulating properties, but more work in this area needs to be done before the question posed in the title can be answered with certainty.

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Biological Nitrogen Fixation Under Early Martian Partial Pressures of Dinitrogen

J. Klingler, R. Mancinelli, M. White

Current climatic and geological evidence suggest that, like early Earth, conditions on primordial Mars may have been favorable for the origin and evolution of life. Evidence from the Viking mission suggests that early Mars had warm temperatures, a dense atmosphere (~1 bar), liquid water, and adequate supplies of certain biogenic elements (C,H,O,P,S). No organic carbon was found on the Martian surface by Viking, however there must have been an influx of organic material from meteorites falling to the surface. Martian water, soil, and SO_2 from volcanic activity would have provided some shielding of a possible early Martian biota from ultraviolet radiation.

Although early Earth and early Mars were similar, one important difference between them was the relative abundance of nitrogen. The only nitrogen reservoir known to exist on Mars is atmospheric N_2. While Earth's atmosphere has always been rich in dinitrogen (pN_2 ~ 780 millibars), primordial Mars is thought to have had a pN_2 of only 18 millibars. Was the difference in the partial pressure of N_2 a factor that prevented the existence, or evolution, of a possible Martian biota?

Our approach was to determine if there are organisms today that can exist under primordial Martian levels of N_2. The rationale for this approach is as follows. On Earth, the ability to fix dinitrogen is of great ecological importance because atmospheric N_2 is, by far, the greatest nitrogen reservoir available to living organisms. Living systems use only "fixed" nitrogen (i.e., organic-N, nitrate, nitrite, ammonia) for growth; but only a small, diverse group of procaryotes are able to biologically fix nitrogen (i.e., convert N_2 to NH_3). Thus, even though N_2 is ubiquitous on Earth, many Earth ecosystems are nitrogen-limited and ultimately depend on biological nitrogen fixation for their survival and growth.

If Earth's extant nitrogen-fixing organisms, which evolved in an environment with a much greater pN_2, can fix N_2 at the low partial pressures of dinitrogen thought to have existed on early Mars, then the low pN_2 of early Mars should not have significantly hindered the existence and possibly the evolution of Martian biota.

We have been investigating the lower pN_2 limit of growth for nitrogen fixation in a variety of procaryotes (including aerobic and anaerobic bacteria and cyanobacteria) to determine if these organisms grow and fix nitrogen at the low pN_2 associated with primordial Mars. We report here the results for two aerobes capable of nitrogen fixation at Martian primordial pressures of dinitrogen. These organisms were studied first because, as aerobes, they have evolved farther from their anaerobic ancestors and would provide a worst-case scenario for adaptation under low pN_2 conditions.

Azotobacter vinelandii and *Azomonas agilis* were grown in nitrogen-free synthetic medium under various partial pressures of dinitrogen ranging from

780-0 millibars (total atmosphere = 1 bar). Below 400 millibars the biomass, cell number, and growth rate decreased with decreasing pN_2. Both microorganisms were capable of growth at a pN_2 as low as 5 millibars, but no growth was observed at a $pN_2 \leq 1$ millibar.

Preliminary data appear to indicate that biological nitrogen fixation could have occurred on primordial Mars making it possible for a biotic system to have played a role in the Martian nitrogen cycle. It is possible that nitrogen may have played a key role in the early evolution of life on Mars, and that later a lack of available nitrogen on that planet (currently pN_2 = 0.2 millibar) may have been involved in its subsequent extinction.

Until more data are supplied by future Mars missions, we cannot address the issue of whether life originated on early Mars. We can speculate that if life did arise, the low pN_2 on early Mars is not a factor which, by itself, would preclude the existence and evolution of a living system. According to this study, extant Earth organisms are capable of fixing dinitrogen at a pN_2 as low as 5 millibars, a value threefold less than the pN_2 condition associated with primordial Mars.

It is conceivable that if organisms were growing (hence evolving) under these low-nitrogen conditions, selection pressure would favor adaptation to even lower partial pressures of N_2 than are possible for current terrestrial organisms. The lower pN_2 limit for other nitrogen-fixing organisms still needs to be determined because we have studied only two out of a diverse group of nitrogen-fixing organisms. One of these organisms could have the potential to fix dinitrogen at a pN_2 of 0.2 millibar. If this were true, the Earth organism would have significant terraforming potential on contemporary Mars by providing fixed nitrogen compounds essential for other microbial species, especially those that can exist under high CO_2/low O_2 conditions.

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Titan Atmospheric Analysis Using Ion Mobility Spectrometry

D. Kojiro, D. Humphrey, N. Takeuchi

Exobiology studies aimed at *in situ* analyses of planetary atmospheres and other environments in the solar system require highly sensitive and specialized instrumentation. These flight instruments must not only be accurate and precise, but they must be able to perform meaningful analyses on small sample amounts under very restrictive conditions.

As one application of such instrumentation in the near future, NASA, in conjunction with the European Space Agency, plans to send a spacecraft to the Saturnian system (Cassini mission) to study Saturn and its satellite, Titan. An analysis of Titan's atmosphere presents a highly challenging task because of the complexity of the analysis, particularly in terms of the many species of organic carbon compounds that may be present, and the very low concentration levels that must be detected. The Ion Mobility Spectrometer (IMS) is one analytical technique that is being developed for this mission.

The IMS is an atmospheric pressure, chemical vapor detector capable of using any one of a variety of host gases, including air, nitrogen, argon, helium, and others. Sample molecules are ionized to form product ions in the IMS reactant region. An electric field moves the ions through a drift tube against the flow of a drift gas where they are separated according to their size and structure. The ion mobility spectrum produced can be used as a fingerprint for sample identification.

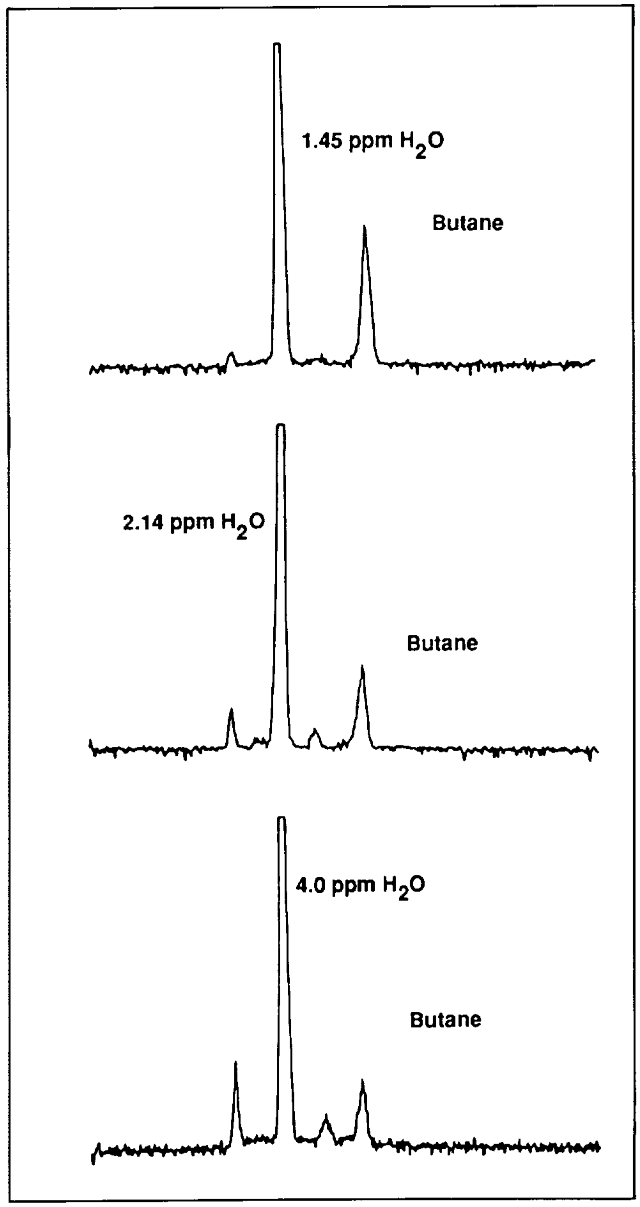
Conventional IMS analysis uses gases which contain trace species, in particular water vapor at multiple parts per million. The water concentration dominates the ion-molecule reaction sequence to produce, in the positive-ion mode, a water-cluster-reactant ion. The water-cluster-reactant ion normally does not readily ionize saturated aliphatic hydrocarbons. Any hydrocarbon ions that may form react immediately, in microseconds, with the high concentration of water vapor normally present. Since these light hydrocarbons are of interest to exobiologists and are expected to be present in trace amounts in Titan's atmosphere, a different IMS ionization mechanism must be found.

One approach to this problem is to reduce the water concentration to the parts per billion range to increase the lifetime of the hydrocarbon ions to milliseconds for measurement. At low water level concentrations, other species may become the predominant reactant ion. An intentionally added chemical, such as methane, can be used to form the reactant ion. Other chemical species may also act as this "reagent gas." The first figure shows IMS spectra of butane with various amounts of water present in dry helium. As the water concentration is reduced, the response to butane increases.

Another approach to improving IMS sample ionization involves designing an IMS reactant region that uses metastable helium. Helium, in the presence of a strong electric field, can be "excited" to a metastable state through collisions with β particles emitted by a radioactive source. These excited helium molecules, metastable helium, can then ionize molecules that have an ionization potential below 19.8 electronvolts. This results in a nearly universal sample ionization mechanism with great sensitivity. Metastable helium is used for sample ionization in the Helium Ionization Detector, a universal, highly sensitive gas chromatographic detector.

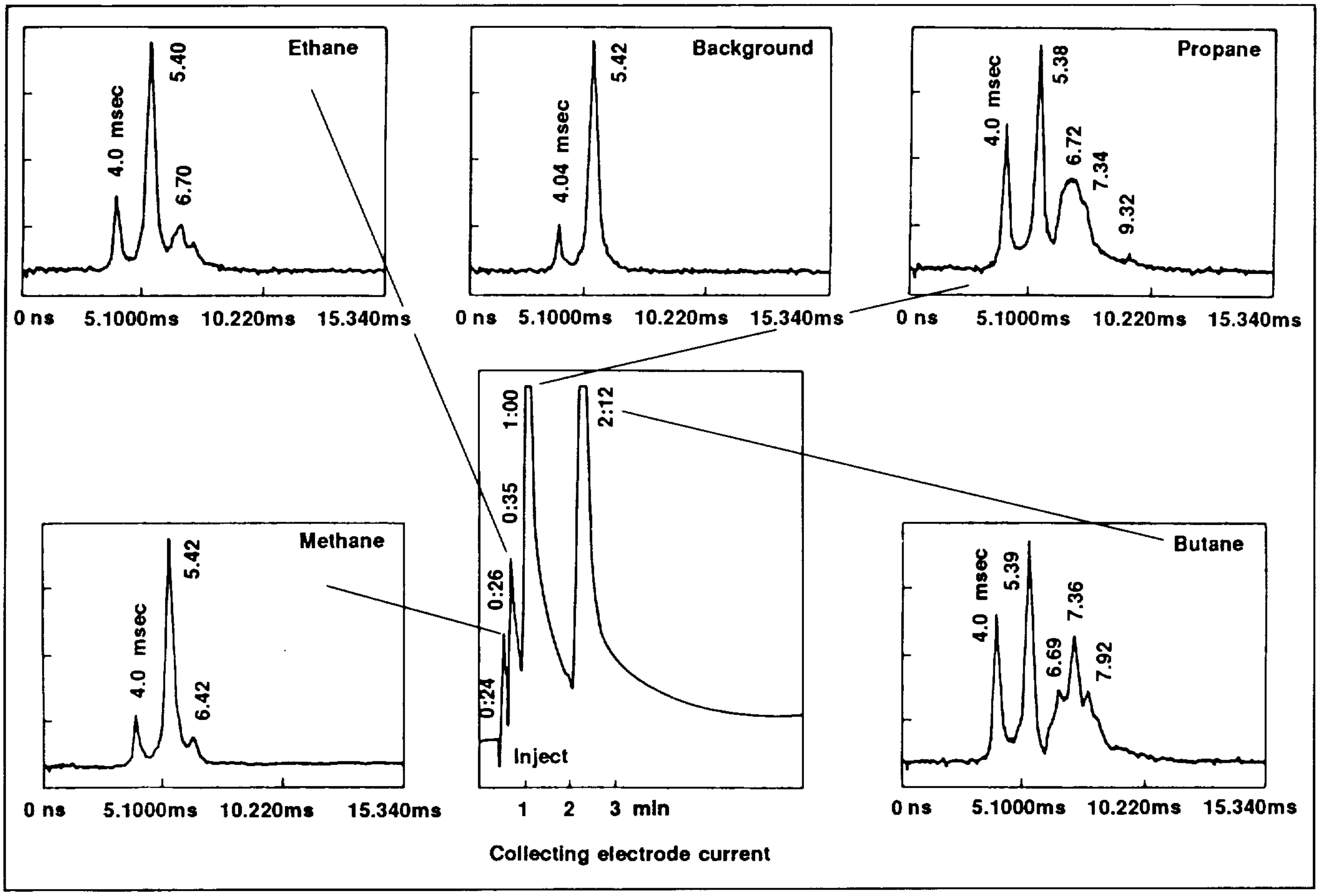
Experiments demonstrating evidence of metastable ionization in the reactant region of the IMS have been conducted using specially designed reactant region electrodes. The ion current levels produced in the IMS under metastable helium conditions, and the manner in which they varied with electric field strength, differed from those in conventional IMS operation.

The IMS, using the Metastable Ionization reaction region, was then used as a detector for a gas chromatograph (GC) and the results are shown in the second figure. The chromatogram was produced by measuring the total ion current at the IMS collecting electrode and is comparable to the total ion current chromatogram produced by a Gas Chromatograph-Mass Spectrometer. Ion mobility spectra were taken of each GC peak and the signals were averaged to produce an IMS spectrum for sample identification.



Sensitivity to butane increases as water concentration decreases

The spectra produced were not as clear as conventional IMS spectra. The strong electric field introduced in the reactant region, to generate the metastable helium, affects the gating, resolution, and collection of the ions. Methods to define the extent of this effect and to control it are now under way. Clearly, though, there is a different manner of sample ionization taking place in the reactant region under these conditions.



Collecting electrode current shows total ion current regardless of drift time. Different Ion Mobility Spectrometer spectra are then produced from each gas chromatograph peak

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Biomarkers and the Search for Extinct Life on Mars

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Geologic and climatologic studies suggest that conditions on early Mars were similar to early Earth. Because life on Earth is believed to have originated during this early epoch (~3.5 billion years ago), the Martian environment could also have been conducive to the origin of life. To investigate this possibility, we must first define the attributes of a possible early Martian biota. Then, specific geographic locations on Mars must be chosen where life may have occurred (i.e., in areas with long-standing water) and within these distinct locations we must search for key signatures or biomarkers of a possible extinct Martian biota.

We have begun defining specific key signatures or biomarkers indicative of past biological activity on Earth that may be applicable to Mars, for example: reduced carbon and nitrogen compounds, Mg, Mn, Fe, and Ni, CO_3^{2-}, SO_4^{2-}, NO_3^- NO_2^-, and the isotopic ratios of C, N, and S.

Our current work includes distinguishing abiotic from biologic origins for these possible biomarkers. For example, abiotically fixed N_2 forms deposits of NO_3^- and NO_2^-; whereas biological fixation and processing produces ammonium and ammonium containing compounds.

Determining the origin of a potential biomarker is not always a straightforward task. For example, on Earth, Precambrian deposits of iron known as Banded Iron Formations occur extensively. It is unclear whether these formations occurred as a result of biotic or abiotic processes. It is known that iron is an important component of biological systems and is concentrated by microbial activity in certain localized areas.

Four hypotheses have been put forth on the origin of the Banded Iron Formations:

1. oxidation of iron via microbial photosynthesis,
2. ultraviolet radiative oxidation of iron,
3. iron oxidation produced by O_2 from microbial mats—and precipitation on top of the mats,
4. O_2 produced from other biological sources elsewhere on the planet oxidizing iron.

We are currently analyzing biomarkers in several model systems, including Antarctic perennially frozen-over lakes, cryptoendolithic microbial systems, paleolake beds in the desert of Nevada, and hypersaline microbial mats. By understanding the processes of formation of certain geological deposits, as well as understanding the origin of reduced carbon and nitrogen compounds and specific isotopic ratios, we can determine whether these signatures would make suitable biomarkers in the search for traces of extinct life here on Earth, and on Mars as well.

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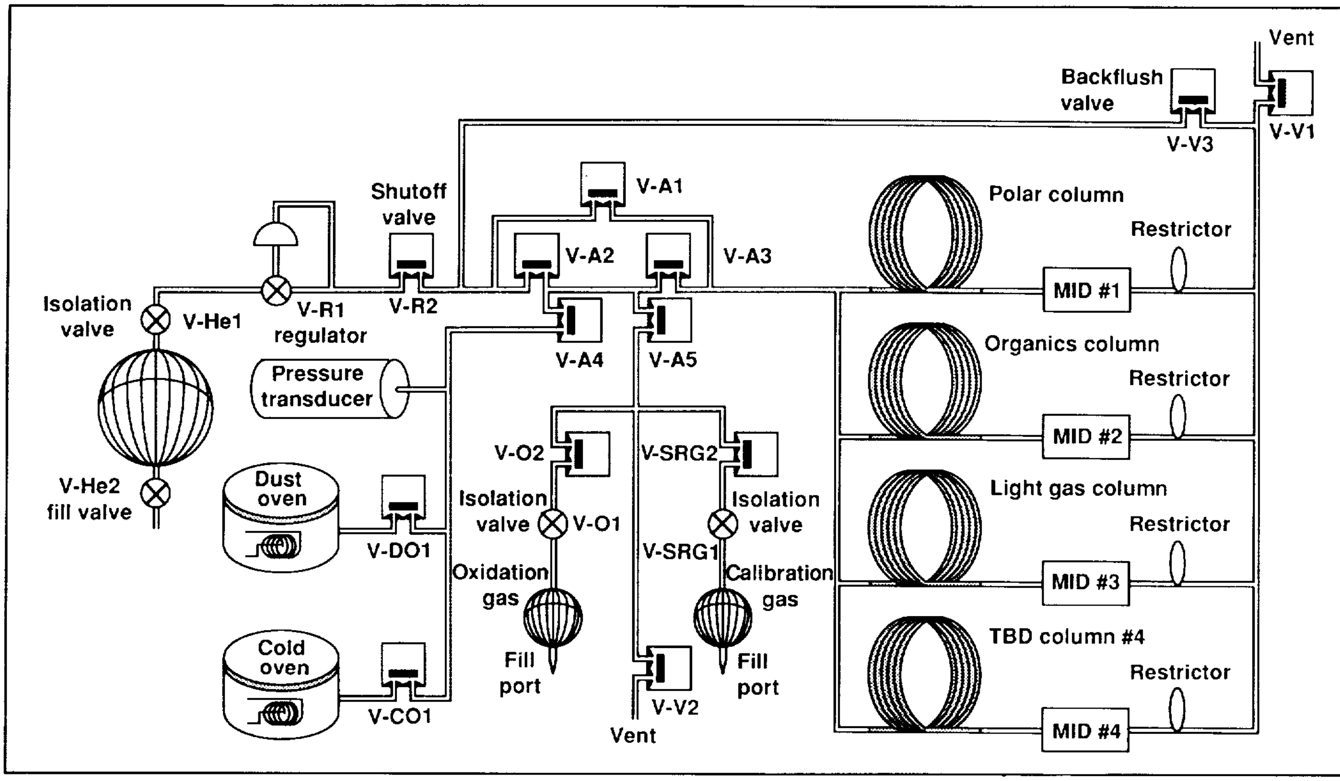
Comet Ice and Dust Gas Chromatograph Instrument

B. O'Hara

The Cometary Ice and Dust Experiment, an integrated gas chromatograph (GC)/X-ray fluorescence spectrometer instrument, has been selected for inclusion on the Comet Rendezvous Asteroid Flyby mission. This instrument will measure the elemental and molecular constituents of collected dust grains, resulting in a greater understanding of the nature of the dust.

The GC, using modulated voltage metastable ionization detectors and a suite of columns, will measure the volatile compounds of the biogenic elements (C, H, O, N, S) thermally released from collected ice and dust grains. Four columns, operated in parallel, have been selected to separate light gases, i.e., N_2, CO, and CO_2; organics and sulfur gases, i.e., alkanes (C6), alkenes (C4), alkynes (C3), COS, H_2S, and CS_2; and polar gases (2), i.e., H_2O, alcohols (C2), aldehydes (C2), nitriles (C3), NH_3, and CH_3NH_2.

As seen in the figure, the GC will have two ovens in which collected ice and dust grains can be placed and heated to various temperatures—the cold oven (≈−100 to 350°C) and the dust oven



Cometary Ice and Dust Experiment gas chromatograph block diagram

(200 to >800°C). The dust oven will have the option of heating in the presence of O_2 to quantitatively oxidize the sample, allowing the elemental C, H, N composition of the sample to be determined. Using a soil with a high organic content as model comet material, parametric studies determined that sample sizes down to 2 micrograms can be quantitatively oxidized when heated to 960°C in the presence of 3% O_2. The minimum detection limits are less than 1 microgram for C and N and less than 2 micrograms for H.

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Mars Exobiology Research Consortium

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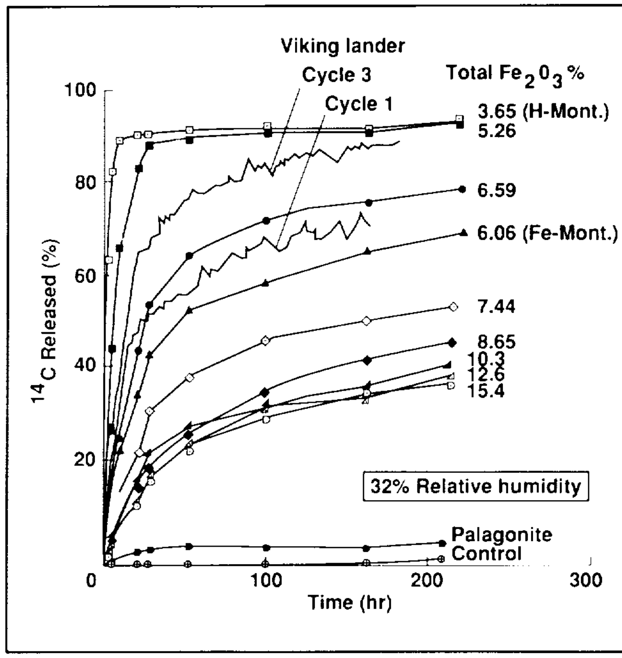
For exobiologists to gain a better understanding of the similarities and differences between the early environments on Earth and Mars, the geochemical and physical aspects of the Martian soil must be studied and elucidated. From these studies exobiologists may be able to answer a primary question in comparative planetology as to why life developed on Earth to its rather complex level and why, apparently, this did not occur on Mars. The soil holds important clues to the processes that shaped the early geological history of Mars and to the possibility of early evolved life or existing life on the planet.

Future Mars missions and Earth-based telescopic observations will supplement existing data and provide significant new data on the surface of Mars. Comparison of Mars surface data with laboratory simulations can provide unusual exobiological insights into this planet, such as the possibility of extant life and as a determinant in selecting exobiologically pertinent landing sites for future Mars missions.

In 1989, some interesting information has been uncovered by the Mars Exobiology Research Consortium. In simulating the labeled release (LR) experiment done by Viking on some terrestrial iron-clay analogs to Mars soil, it was shown that factors such as water and iron content of the clay, preheating, and addition of various mineral carbonates influenced the results of the LR experiment. When the LR experiment was run with palagonite (a weathering product of volcanic basaltic glass which also contains iron), the results indicated a poor correlation with the Viking LR results (see the first figure).

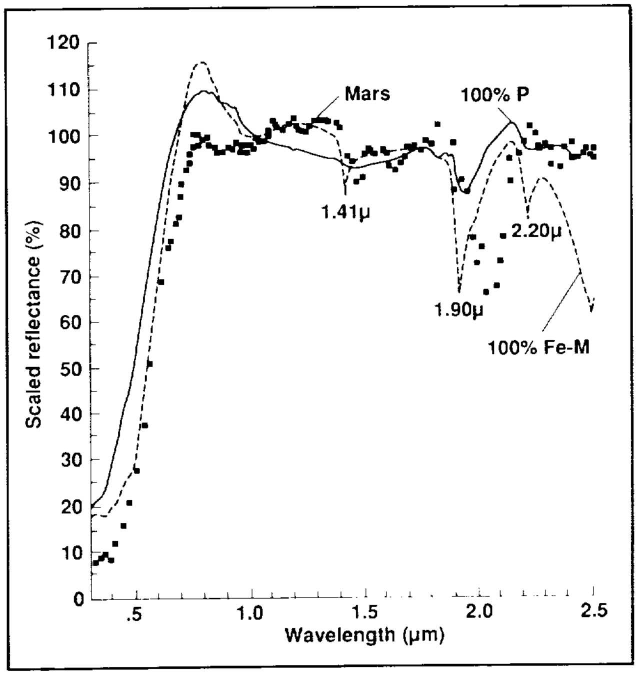
It was concluded that iron having an extremely small particle size may be associated with a smectite-montmorillonite clay in the Mars soil. It is likely that sulfate and chloride salts are present as accessory minerals in the Martian soil. Carbonates may also be present, but at very low concentrations.



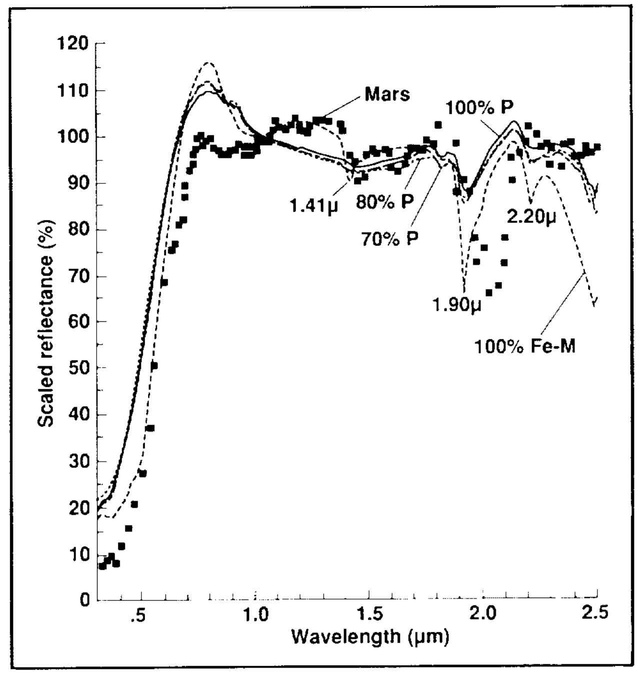
Plot of Carbon-14 released as carbon dioxide versus time from the labeled release experiment at 32% relative humidity. VL refers to Viking Lander

Reflectance spectroscopy of mixtures of montmorillonite clay and palagonite, proposed mineral analogs of the Martian soil, were obtained in the laboratory in the spectral range from the ultraviolet to the infrared. Both analogs are considered good spectral analogs of the Martian soil, with palagonite being favored by spectroscopic investigators (see the second figure). The study concluded that in the mixtures of palagonite and montmorillonite clay, up to 30% by weight of clay (70% by weight palagonite) can exist without being detected spectroscopically (see the third figure).

From these two conflicting experimental results (LR and reflectance spectroscopy), it must be expected that the mineralogy of Mars will be complex. The Mars lithosphere, like Earth's, has been and still is interacting with the atmosphere. This is likely to produce secondary minerals as weathering or alteration products as a mixture of minerals composing the soil.



Comparison of the diffuse reflectance spectra of palagonite and iron-montmorillonite containing 15.4% iron as iron oxide with the Mars reflectance spectrum. All spectra are scaled to unity at 1.02 micrometers



Comparison of the diffuse reflectance spectra of mixtures of palagonite and iron-montmorillonite with the Mars reflectance spectrum. All spectra are scaled to unity at 1.02 micrometers

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Mechanism of Ion Binding by Simple Carrier Molecules

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A major event and a turning point in protobiological evolution was the emergence of the first self-replicating systems which could multiply and preserve their biological material and functions. Part of the NASA Exobiology program focusing on the study of the origin and evolution of life has as a central goal to understand how protocells could perform their necessary functions in the absence of the complex cellular apparatus used by modern cells.

An essential function of a cell is the transport of ions across its membrane walls in a specific and controlled manner. Ions, such as sodium, potassium, chloride, or calcium, mediate most of the essential biochemical processes in a present cell and must have played a similar role early on. Energy acquisition and transfer, enzymatic catalysis, the reading of the genetic code, and the transmittal of neural and muscular signals all require precisely regulated ion concentrations.

Ion transport across the cell membrane is a complicated process because water, which is on both sides of the membrane (outside and inside the cell) forms a favorable, stable environment for ions. On the other hand, the membrane interior is highly unfavorable for ions, and spontaneous penetration of the membrane by an ion is an unlikely event. Therefore, moving an ion across a membrane requires assistance which comes in present cells from specialized, large molecules incorporated into the membrane. These molecules capture ions from water, carry them through the membrane, and release them on the other side. The molecular mechanism of this process, however, is poorly understood.

Since ion transport was essential for the biochemical and biological evolution of protocells, it is of great interest to understand how ion binding and transfer across membranes can be mediated by molecules much less complex than present ion carriers. Recently a class of simple, specific ion-binding molecules was discovered. These molecules are excellent models for detailed studies of the ion binding mechanism and we performed such a study.

To model the ion binding process we used the computational method of molecular dynamics. The system under study consisted of the ion, the carrier molecule, and several hundred water molecules. The behavior of this system was simulated by numerically solving Newton's equations of motion for each atom in the system. During the course of a typical simulation the ion moves toward the carrier and eventually is removed from its aqueous environment to the interior of the carrier.

Analysis of the results led to the thorough understanding of selective and efficient ion binding by simple carriers. These molecules have structures that properly balance rigidity and flexibility. Structural rigidity is needed to ensure selective binding. Flexibility, on the other hand, is necessary to reduce the energy barrier to ion capture and, therefore, increase the efficiency of binding.

Reduction of the energy barrier is also accomplished by strong, favorable electrostatic interactions between the ion and charged groups of the carrier and by removal of water molecules tightly bound to the ion stepwise rather than simultaneously. The effectiveness of capture is further increased by funneling the ion into the carrier.

Upon binding the ion, many carriers undergo change in which groups of atoms with high affinity to water come into close contact with the ion and get buried in the interior of the carrier. Simultaneously, groups soluble in oil become exposed to the surface, allowing the complex to penetrate the oily interior of the membrane.

Subsequent analysis of known structures of ion channels and carriers from modern cells revealed that they possess structural features allowing for the same mechanism of ion transport. Similar features are also required for efficient molecular recognition and enzymatic catalysis. Thus, our study lends support to one of the main concepts in studies of biochemical evolution: that physicochemical mechanisms of ubiquitous cell functions have remained similar throughout evolution, but became more accurate and efficient as the molecules performing these functions gained structural complexity.

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CO_2 Levels and Marine Plankton $^{13}C/^{12}C$

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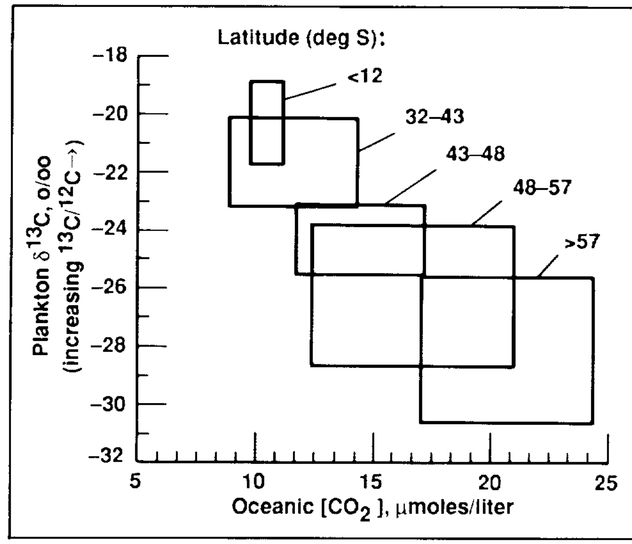
During 1989 research was conducted on carbon isotopic abundances naturally present in marine plankton. Our research (which combines efforts of researchers from University of California, Santa Cruz; Lamont-Doherty Geological Observatory; and Ames Research Center, as well as the research of others) has shown that the ratio of carbon-13 to carbon-12 ($^{13}C/^{12}C$) in the soft tissues of marine plankton dramatically decreases with increasing latitude in the Southern Hemisphere (see the figure). It is notable that the much lower $^{13}C/^{12}C$ in high-latitude Antarctic plankton is very similar to the plankton isotope ratios that were present throughout the ocean millions of years ago, as preserved in the marine sedimentary record. What does this tell us about present-day biogeochemistry in high-latitude oceans? Is there a connection to ancient marine environments?

It has been hypothesized that the lower $^{13}C/^{12}C$ of organic matter present in much of the marine sedimentary record was the consequence of substantially elevated CO_2 concentrations in the oceans and atmosphere through most of Earth's earlier history. This idea arose from experiments that showed that phytoplankton, the primary producers of marine organic matter, can more strongly select for ^{12}C (and against ^{13}C) under circumstances in which there is abundant CO_2. The consequence of this enhanced isotopic selectivity is to lower the $^{13}C/^{12}C$ in the organic matter produced. These observations have been used to interpret the lower $^{13}C/^{12}C$ in, for example, the Cretaceous Period (66-144 million years ago) as a product of at least several times greater CO_2 concentrations during that time than at present.

Does the same mechanism then also explain the similar plankton ^{13}C depletion in today's Antarctic Ocean? To test this idea we obtained previously unpublished records of the partial pressure of CO_2 in surface seawater from many locations in the Southern Ocean and Antarctic waters. Converting these partial pressure measurements to true CO_2 concentrations using a known, temperature-dependent relationship (Henry's law) revealed that cold, high-latitude waters contain as much as 2.5 times more CO_2 than do equatorial warm waters (see the figure).



Plot of the relative $^{13}C/^{12}C$ of planktonic organic matter versus the dissolved CO_2 concentration in seawater. Each box contains all data relevant to the southern latitudes indicated

Furthermore, as expected, the trend in surface water CO_2 concentration with increasing latitude correlates inversely with the latitudinal trend in plankton $^{13}C/^{12}C$ (see the figure). This provides further support for a strong link between variations in oceanic CO_2 concentration and plankton $^{13}C/^{12}C$.

Carbon isotope abundance in marine plankton or their sedimentary remains may therefore provide a record of CO_2 abundance and its biological utilization in present or past oceans. Isotopic measurements, performed with other indices of CO_2 and biological productivity, will document past changes that have occurred in the marine environment.

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Chaos and the Universe

J. Scargle, J. Cuzzi

Two kinds of disorder can occur in nonlinear dynamical systems:
1. Chaos—evolution following simple deterministic laws, but nevertheless appearing disordered because of the mixing ("stretch and fold") character of the dynamics.
2. Randomness—fundamentally unpredictable evolution of a complex system (i.e., one with many degrees of freedom).

Chaotic motions of planets, satellites, and ring particles appear to be important in the long-term evolution of the solar system. In addition, apparently disordered time series data from any nonlinear system could be either chaotic or random (or a mixture of the two). New time series analysis techniques can detect, model, and separate the two kinds of processes.

Both chaotic and random processes can be represented as filtered versions of a basic uncorrelated process, and deconvolution techniques to recover the filter shape and the dynamics of the underlying process have been developed, tested on simulated data, and applied to a variety of experimental time series data. These and other techniques will be used to study stochastic brightness fluctuations of astronomical objects, chaotic motions of solar system objects, and a variety of other astrophysical systems.

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The Anomalous Interstellar Polycyclic Aromatic Hydrocarbon Features

W. Schutte, A. Tielens, L. Allamandola

We have studied the strong anomalous 3.43 and 3.53 emission features in the infrared spectra of the sources Elias 1 and HD 97048. These sources both are so-called protostars; that is, stars which are still being surrounded by the accreting cloud of dense interstellar matter from which they were formed. Besides the anomalous emission features, these objects also show the more commonly observed family of emission features at 3.3, 6.2, 7.7, 8.7, and 11.3 micrometers. It is generally assumed that these features are emitted by polycyclic aromatic hydrocarbon molecules which have been excited by the absorption of one or more ultraviolet photons. Combining our results with earlier observational data shows that the anomalous bands are emitted from within 10 astronomical units (1.5×10^9 kilometers) of HD 97048, while the general infrared features are emitted at least out to 4000 astronomical units.

By studying laboratory spectra, we found that large polycyclic aromatic hydrocarbons such as coronene ($C_{24}H_{12}$) have weak infrared features that correspond quite well with the observed anomalous 3.43- and 3.53-micrometer emission features. These bands are due to overtones and combination bands of the vibrational modes of the carbon skeleton of these molecules.

If such an identification is correct, the large intensities of the anomalous features of HD 97048 and Elias 1 relative to the common emission features of the polycyclic aromatic hydrocarbons suggest that they are emitted by highly excited, super large molecules containing a high amount of carbon relative to hydrogen. This is consistent with theoretical modeling, which indicates that in the observed emission zone of the anomalous features within 10 astronomical units from the star, only very large polycyclic aromatic hydrocarbons containing more than 500-1000 carbon atoms can survive the high excitation induced by the absorption of the ultraviolet radiation from the star.

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Infrared Astronomical Satellite Low-Resolution Spectral Observations of H II Regions

J. Simpson, R. Rubin

As a result of star formation and evolution, the abundance of the elements changes with time in a galaxy; variation with position in a galaxy is consequently a function of the amount and type of star formation. It has long been known that the abundance of nitrogen and oxygen relative to hydrogen decreases with increasing distance from the center of our galaxy (such a decrease is called a "gradient"). This is attributed to increased star formation in the inner galaxy where the density of gas and dust is higher.

Oxygen is produced in massive stars, whereas nitrogen is produced in both massive stars and stars of lower mass, such as the mass of the Sun. This difference is apparent in that the N/H gradient is steeper than the O/H gradient in galaxies. Neon and sulfur, which are also produced in massive stars and returned to the gas in the galaxy by supernovae, heretofore have not been well studied.

Researchers at Ames Research Center have determined the abundance of neon and sulfur for 95 H II regions whose spectra were measured by the Infrared Astronomical Satellite (IRAS) Low-Resolution Spectrometer. Because of the large size of the sample, a number of correlations can be studied. Abundance decreases with distance from the galactic center. The Ne/H gradient is similar to previous observations of the O/H gradient, showing that oxygen and neon are made in similar types of stars. The S/H gradient is not as steep; sulfur must be produced in a somewhat different type of star. The abundance of neon and sulfur is also higher for low-luminosity stars; that is, stars of lower mass. This luminosity correlation can be attributed to variations in the initial mass function (IMF), such that there are few or no high-mass stars produced when the abundance is high.

The neon ionization (Ne^{++}/Ne^{+}) is high only for sources with both low neon abundance and high luminosity. The reasons are that only stars with high effective temperatures produce the 41 electronvolt photons necessary to ionize neon to Ne^{++}; such stars also have high luminosities. Abundance must be low so that the opacities are low enough to let these high energy photons through.

A correlation of ionization and abundance has also been noted in extragalactic H II regions, where it has been attributed to variations in the IMF as a function of abundance; again, such that all high-mass stars have low abundances.

The total IRAS far-infrared luminosities and ultraviolet luminosities of the sources were compared to those predicted for zero-age main sequence stars. The H II regions all lie close to the main sequence line, showing that all or almost all the stellar flux must be absorbed by the infrared-emitting dust. Many of the H II regions are more luminous than the most massive stars ever seen; they are probably excited by several stars or even a cluster of stars. The ionization of neon, as compared to that of model H II regions, shows that the effective temperatures of the exciting stars cannot be more than 40,000 Kelvin, whereas it is thought that the most massive stars are hotter than 40,000 Kelvin. A possible explanation is that these very massive stars have far-ultraviolet spectra cooler than the 45,000-50,000 Kelvin effective temperatures that are found for their visible and near-ultraviolet spectra.

This research was supported by the IRAS General Investigator Program.

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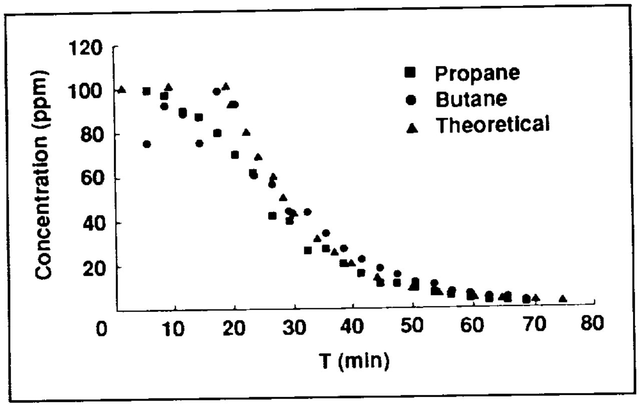
Multiplex Gas Chromatography for Sampling Changing Sample Concentrations and Compositions

J. Valentin, K. Hall

As currently practiced, conventional gas chromatography (GC) has two important limitations in atmospheric analysis. Firstly, detector sensitivity is limited by the sample volume. Only small sample volumes may be introduced into the column and these samples are further diluted by carrier gas during chromatographic separation. Secondly, only discrete samples may be accepted. Sufficient time must pass between discrete sample injections for the most strongly retained substance to elute from the column.

A good illustration of this is what happens when a probe passes through a planetary atmosphere. Even though conventional GC has been useful in spacecraft missions to Mars by the Viking Mars lander and the Pioneer Venus probe, there has been time for analysis of only a few discrete samples taken at points along the trajectory through the atmosphere. No GC information was obtained on the chemical composition of the atmosphere between those points.

In recent years the Solar System Exploration Branch has conducted research in the area of multiplex gas chromatography (MGC) to determine its potential (1) for use in a spacecraft or any other restricted environment and (2) as an alternative in dealing with these limitations. In MGC many samples are pseudorandomly introduced into the chromatograph without regard to the length of time required for individual analysis. A new sampling may begin as often as every few seconds, allowing the monitoring of the whole sample stream while it is being acquired. However, the chromatograph must be



Exponential dilution calibration curve for propane and butane. The starting concentration for both propane and butane was 100 ppm

under computer control and the final chromatogram can only be obtained computationally by applying deconvolution techniques such as Fourier Transforms to the detector output data. Since more samples are introduced an improvement in sensitivity can be achieved.

To simulate a real planetary atmospheric GC analysis, studies were performed in which the sample was changing composition as a function of time by using an exponential dilution flask. This is similar to what a probe would sample while it is descending through an atmosphere. Preliminary results have demonstrated the feasibility of MGC for a changing sample composition.

The analyses were performed by diluting a mixture of hydrocarbons containing propane and butane with helium. As shown in the figure, the experimental values compare favorably with the predicted (theoretical) ones.

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Evolution of the Spectrum of Supernova 1987a

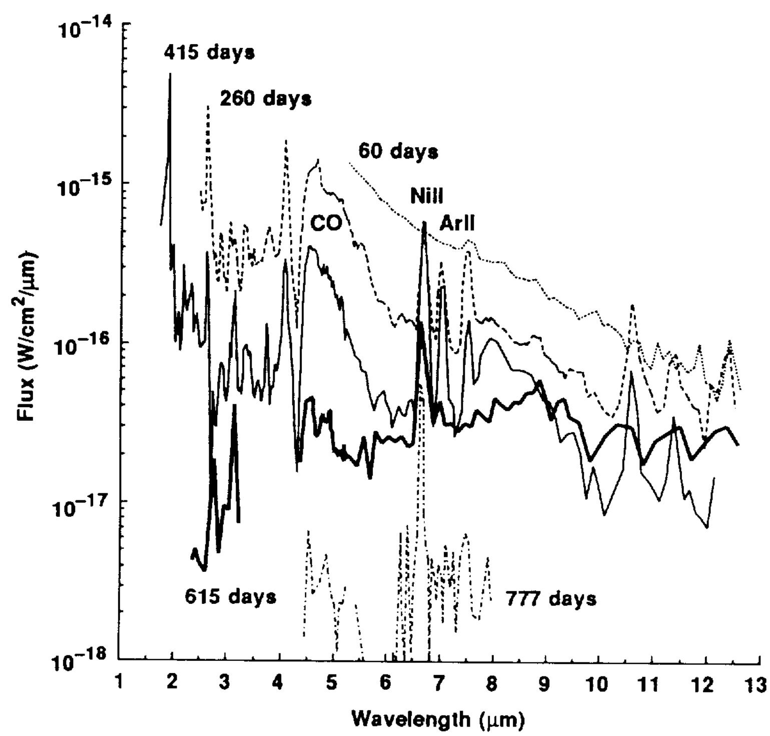
D. Wooden, J. Bregman, F. Witteborn

Astronomers continue using the Kuiper Airborne Observatory (KAO) to measure changes in the infrared spectrum of the ejecta from the exploding star whose death was witnessed on Earth February 23, 1987.

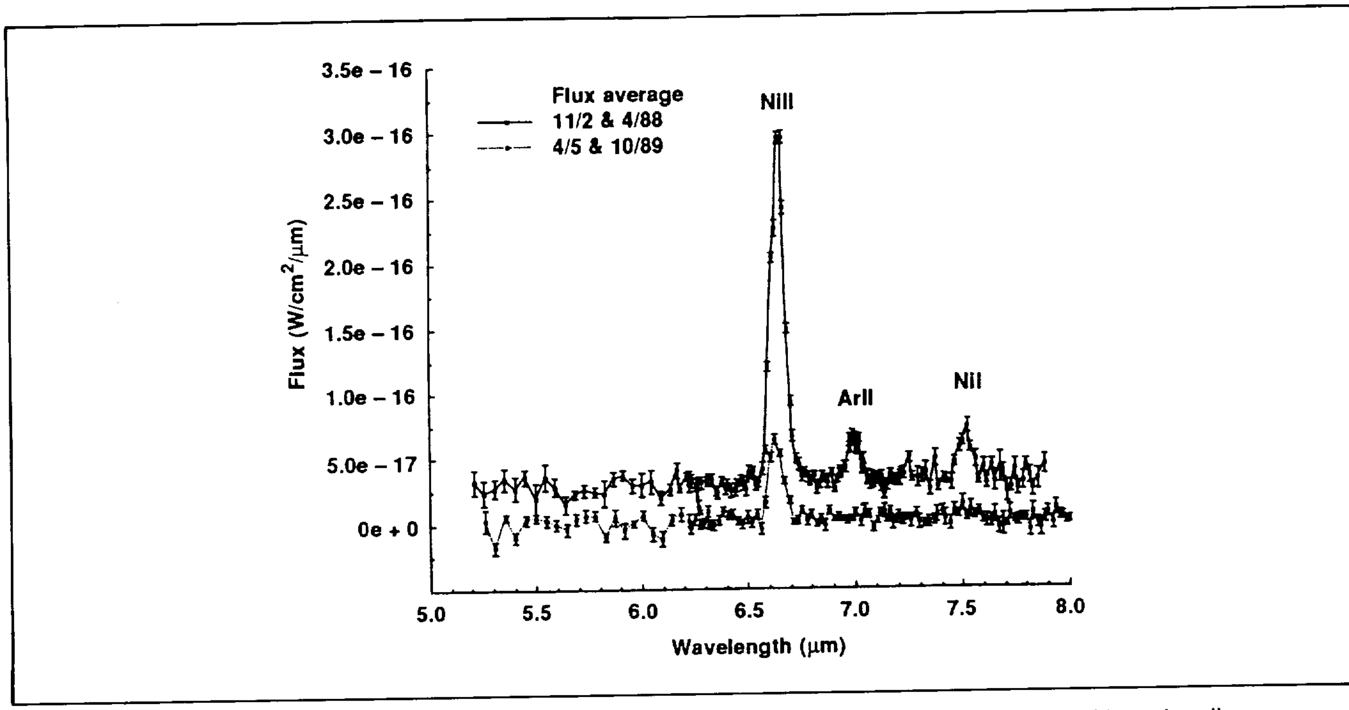
The first figure shows five different spectra taken from the KAO from April 1987 (the top dotted line) to April 1989 (the bottom dash-dot line). Spectra taken in October 1988 (darkest solid line) showed a significant increase in the thermal (~300 Kelvin) component of continuum radiation which has subsequently been attributed to grain formation in the ejecta.

The NiII line (6.634 micrometers) remained prominent relative to the continuum even in April 1989 when the previously strong ArII line (6.983 micrometers) had disappeared (see the second figure). The NiII line profile continued to show an ejecta average expansion velocity of 1400 kilometers/second.

The interesting anomalous red shift caused by electron scattering in an earlier phase of the explosion had disappeared by April 1989, as would be expected when the electron density had decreased. No evidence for a pulsar was found in the 2-8 micrometer spectra; however, estimates of dust opacity show that the pulsar radiation may be obscured in the infrared and visible spectra. The spectra were obtained with two multiple-detector, grating instruments developed at Ames Research Center: (1) Faint Object Grating Spectrograph (FOGS) covering the 5-10 micrometer range, and (2) Shortwave Infrared Array Spectrograph (SIRAS) covering the 2-5.5 micrometer range.



The infrared spectra of SN1987A observed at five epochs using the SIRAS and the FOGS aboard the Kuiper Airborne Observatory. The spectra exhibit successively lower continua except at 615 days where a strong thermal peak appears. It is believed to arise from dust formation in the ejecta of the supernova. The sharp peaks are emission lines from hydrogen and from material found inside the supernova including nickel, argon, and cobalt from the exploded stellar core. The broad peak near 4.5 micrometers is from carbon monoxide (CO)



Comparison of SN1987A spectra in November 1988 (615 days) and April 1989 (777 days). Note the disappearance of ionized argon radiation and the dramatic decrease in the nickel radiation and the continuum. These spectra were taken by the FOGS from the Kuiper Airborne Observatory at a resolution about five times higher than that shown in the first figure

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Annihilation of Life

K. Zahnle

The Age of Dinosaurs was brought to a sudden end by the impact of a comet or small asteroid. How the impact actually caused mass extinction, and why the survivors survived, remain open questions. An enormous amount of soot has been found at the Cretaceous/Tertiary boundary. So much soot, in fact, that it appears that most of Earth's forests must have burned to the ground. Atmospheric re-entry of small particulate ejecta ballistically launched from impact craters offers a plausible mechanism for kindling fires globally. The energy these particles deliver is approximately globally uniform, and is estimated to have been a significant fraction of the energy released by the impact. The hot particles form an optically thick layer that radiates as a global black body with a temperature on the order of 1000 Kelvin for some tens of minutes. The far-reaching consequences of the Cretaceous/Tertiary impact clearly indicate that even today impact cratering can be an important influence on life on Earth.

The lunar surface retains a record of a vastly larger cratering flux that must also have characterized Earth's earliest environment. Not only were impacts much more numerous, the largest ones—the basin-forming impacts, some occurring as recently as 3.8 billion years ago—were vastly larger than the Cretaceous/Tertiary event. Still greater impacts must have occurred at earlier times, probably including an impact on Earth forming the moon itself. Given this context, it is obvious that many impacts occurred capable of annihilating life on Earth. The origin of life as we know it must postdate the last such impact.

Working with Prof. Norman H. Sleep of Stanford University, I have sought to place limits on the magnitude and timing of this event. We used the last impact that boiled off the oceans as a proxy for the last planet-sterilizing event. We find that an impactor roughly the size of the large asteroids Pallas and Vesta would have completely evaporated the oceans. From the lunar-cratering record we deduce that such a potentially global-sterilizing event is not improbable as recently as 3.8 billion years ago, although 4.1 or 4.2 billion years ago are better estimates.

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16. Abstract

Selected research and technology activities at Ames Research Center, including the Moffett Field site and the Dryden Flight Research Facility, are summarized. These accomplishments exemplify the Center's varied and highly productive research efforts for 1989.

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